OCS Study
MMS 92-0060

DESIGN AND TESTING OF A MONITORING PROGRAM FOR BEAUFORT SEA WATERFOWL AND MARINE BIRDS

by

for

U.S. Department of Interior
Minerals Management Service
Procurement Operations, MS 2500
381 Elden Street
Herndon, VA 22070

Contract 14-35-0001-30491
LGL Report TA 863-1B

November 1992

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by

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This report has been reviewed by the MMS and approved for publication. The opinions, findings, conclusions, or recommendations expressed in the report are those of the authors and do not necessarily reflect the views or policies of the MMS. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

PROJECT AND REPORT ORGANIZATION

This project was conducted by LGL Limited, environmental research associates, Sidney, British Columbia, through a contract from MMS to LGL Alaska Research Associates, Inc., Anchorage, Alaska. The study was conducted in cooperation with Golden Plover Air, Inc., Colville Village, Alaska, and W.J. Gazey Research, Victoria, British Columbia. Golden Plover Air provided the Cessna 206 aircraft, pilot, and field logistics support associated with the aircraft for all of the surveys during 1989 through 1991. W.J. Gazey helped with statistical analyses and interpretations.

The contract award for this project was 25 July 1989 and project initiation was on 8 August 1989, when we tested the idea of conducting several aerial surveys of the study areas over a short time period (three surveys within a 5- to 7-day period).

An earlier report was submitted to MMS in November 1990 (Johnson 1990). That report presented the proposed design and rationale for the Beaufort Sea waterfowl and marine bird monitoring protocol. The design was based on an extensive analysis of nine years (1977-1984 and 1989) of aerial survey data in the study area for the focal species, the oldsquaw duck (*Clangula hyemalis*). Based on the results of a multivariate analysis of various factors affecting the distribution and abundance of old squaws in the study area during the nine earlier years, the design report proposed a statistically rigorous sampling program and an analysis of variance model for analyzing data collected during the testing phase of the study — in 1990 and 1991. The testing phase provided an opportunity to test the original study design and to make recommendations for improvements. This final document reports on both the design and testing phases of the study.

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ABSTRACT

The purpose of this project was to design and test a monitoring protocol for marine birds in the Jones-Return islands area of the central Alaska Beaufort Sea. Because of its overwhelming and widespread abundance, relatively sedentary behavior, ease in counting, and the extensive historical database, the oldsquaw duck (*Clangula hyemalis*) was selected as the focal species for this study. Two null hypotheses were formulated concerning potential changes in the numbers and distribution of oldsquaws in relation to petroleum development in the Industrial area, compared to a Control area located about 50 km to the east.

A 9-year historical database was analyzed using multivariate techniques to determine which of several predictor variables recorded during past aerial surveys were significantly related to oldsquaw density in the study areas. Separate analyses were conducted for the 5 June to 23 September period, and for the mid July to late August-early September molt period of oldsquaws. The results of the two multiple regression analyses indicated that about 57% and 6870, respectively, of the total variation in oldsquaw density during the two periods could be explained by predictor variables recorded during aerial surveys. Predictor variables representing habitat, day of the year, time of day, amount of ice, and wave height recorded on transect during the survey were most closely associated with oldsquaw density. Measurement error and influences outside the study area no doubt also had a strong influence on the results.

Based on results of regression analyses of historical data, an intensive program of aerial surveys and an analysis of covariance (ANCOVA) statistical procedure were designed and tested in 1990 and 1991. The 2-year testing phase of the study resulted in several revisions to the originally proposed sampling procedures, to the survey schedule, and to the recommended statistical procedures. Results of the ANCOVA indicated that, during the 2-year testing phase of the study, there was no evidence of a change in oldsquaw densities that may be attributable to disturbance in the Industrial study area. Other analyses indicated that the revised sampling and analysis procedures would be adequate to detect long-term trends in oldsquaw density and localized disturbance effects, but that the monitoring program needs to be continued well beyond the two years of the current study.

ACKNOWLEDGEMENTS

This study was funded by the U.S. Department of Interior, Minerals Management Service (MMS), Alaska OCS Region, Anchorage, Alaska. We thank Steve Treaty, Cleve Cowles, and Jerry Imm of MMS for their help during this study. We also thank Rod King, U.S. Fish and Wildlife Service, Office of Migratory Bird Management, Fairbanks, Alaska, for kindly providing summaries of aerial breeding pair surveys of oldsquaws on the Arctic Coastal Plain of Alaska.

Most of LGL's earlier studies of marine waterbirds in the central Alaska Beaufort Sea were funded and supported by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), and the U.S. Department of Interior, Bureau of Land Management (BLM) and MMS, through the Outer Continental Shelf Environmental Assessment Program (OCSEAP). Other studies were supported by Shell Oil Company, and by ARCO Alaska Inc. for the U.S. Army Corps of Engineers. We thank R.B. Metcalfe and N.L. Space, Spill Response Specialists with ARCO Alaska, Inc., Kuparuk Operations, for providing information on industry activities in the Industrial study area.

Rolph Davis, Alan Birdsall, Joe Truett, Benny Gallaway, Tom Wetmore, John Richardson, Scott Anderson, Josh Baker, DeClan Troy, Lynn Maritzen, Brian Harvey, and many others at LGL provided management and/or technical assistance during some of our government and industry sponsored studies of marine birds in the Beaufort Sea.

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Joe Truett, Randall Howard and Bob Pollard were instrumental in recovering some of the historical aerial survey data. We especially thank Peter Wainwright, Gary Searing, and Dave Wiggins for working tirelessly to help reformat, reorganize, and clean-up the historical aerial survey data.

John Richardson (LGL Limited) contributed significantly to the experimental design for this study and suggested improvements to this report; he also advised on some statistical matters. Rolph Davis also helped design the study, and has helped in the management of the project. William Griffiths helped obtain missing weather data for some survey periods and gave advice regarding weather and oceanographic influences (seasonal upwelling potential) in the study area. Karen Doiron was instrumental in the production of this report.

INTRODUCTION

In this introduction and the following section of the report, we review the purpose and objectives of this study and provide background information about the original design phase of the study (Johnson 1990). In the last half of the report we present results and interpretations from the 2-year testing phase of the study.

The Outer Continental Shelf Lands Act (OCSLA) and its amendments include provisions for (1) post-lease monitoring studies to provide information that can be compared with any previously collected information in order to identify significant changes in quality and productivity of leased environments, (2) establishing trends in the areas studied and monitored, and for (3) designing experiments to identify the causes of such changes.

The purpose of this project was to design and test a monitoring protocol for marine waterbirds, principally marine waterfowl, in nearshore waters of the Alaska Beaufort Sea: waterfowl are abundant in this area (Johnson and Richardson 1981, Johnson and Herter 1989). The need for such a protocol is most urgent in the central Beaufort Sea area (e.g., Jones-Return islands area), where nearshore exploration and coastal development have occurred over the past decade, and are likely to escalate in the future.

In late September 1983, a MMS / NOAA-sponsored workshop was held in Girdwood, Alaska, to develop a monitoring strategy for the Alaska Beaufort Sea (Dames and Moore 1984). The concept of monitoring Beaufort waterbirds is based on the following conclusions of the 1983 workshop:

> Marine birds are abundant and are a biologically and socially important component of the nearshore Beaufort Sea ecosystem.
>
> Some species of Beaufort Sea marine birds, especially marine waterfowl such as the oldsquaw duck (*Clangula hyemalis),* are ubiquitous, relatively easy to detect and count, and have been well studied prior to industrial development; therefore they are appropriate candidates for monitoring.
>
> A monitoring protocol should be designed to insure that industry-related influences on marine birds are discernible from other natural

influences, i.e., should involve a rigorous design and statistical approach that includes both experimental (Industrial) and Control areas and draws on all relevant historical information collected in the study area.

The 1983 workshop identified several potential waterbird species for monitoring. The oldsquaw duck was selected by the workshop over other species because it is the most abundant and widespread local waterbird in the nearshore Beaufort Sea, the zone where virtually all exploration and development have occurred in the Beaufort marine system. Data presented at the workshop confirmed that during the summer open-water period oldsquaws represent most of the avian biomass in the nearshore Beaufort environment. During July and August, when they molt their feathers, they are flightless and thought to be particularly vulnerable to water-borne contaminants and disturbances. They are overwhelmingly the most abundant species of bird in the study area throughout the open water period (Fig. 1). *No* other species of waterbird is present in sufficient numbers in the study area for a period of time long enough to be considered a suitable candidate for monitoring. Nevertheless, we have reviewed and compared the suitabilities of other possible candidate species for the monitoring program.

Several hundred Pacific eiders (*Somateria mollissima v-nigra*), Arctic terns (*Sterna paradisaea*), glaucous gulls (*Larus hyperboreus*), and brant (*Branta bernicla*) nest and rear their young on barrier islands in the central Alaska Beaufort Sea, but their numbers are too few (eiders, terns, gulls, brant), their distributions too clumped (eiders, gulls, terns, brant) and their habits too secretive (eiders, brant, terns) for them to be considered suitable candidates for monitoring without intensive ground-based monitoring.

Thousands of juvenile phalaropes and hundreds of Arctic terns and glaucous gulls move to barrier island habitats to feed starting in early August, prior to their southward fall migration (Johnson and Richardson 1981). But the year-to-year variations in the numbers of these species encountered in Beaufort Sea habitats are great (Johnson and Richardson 1981, Johnson 1984c). In years with high reproductive success at tundra nesting locations, there are many juvenile phalaropes, gulls and terns along the barrier islands in August

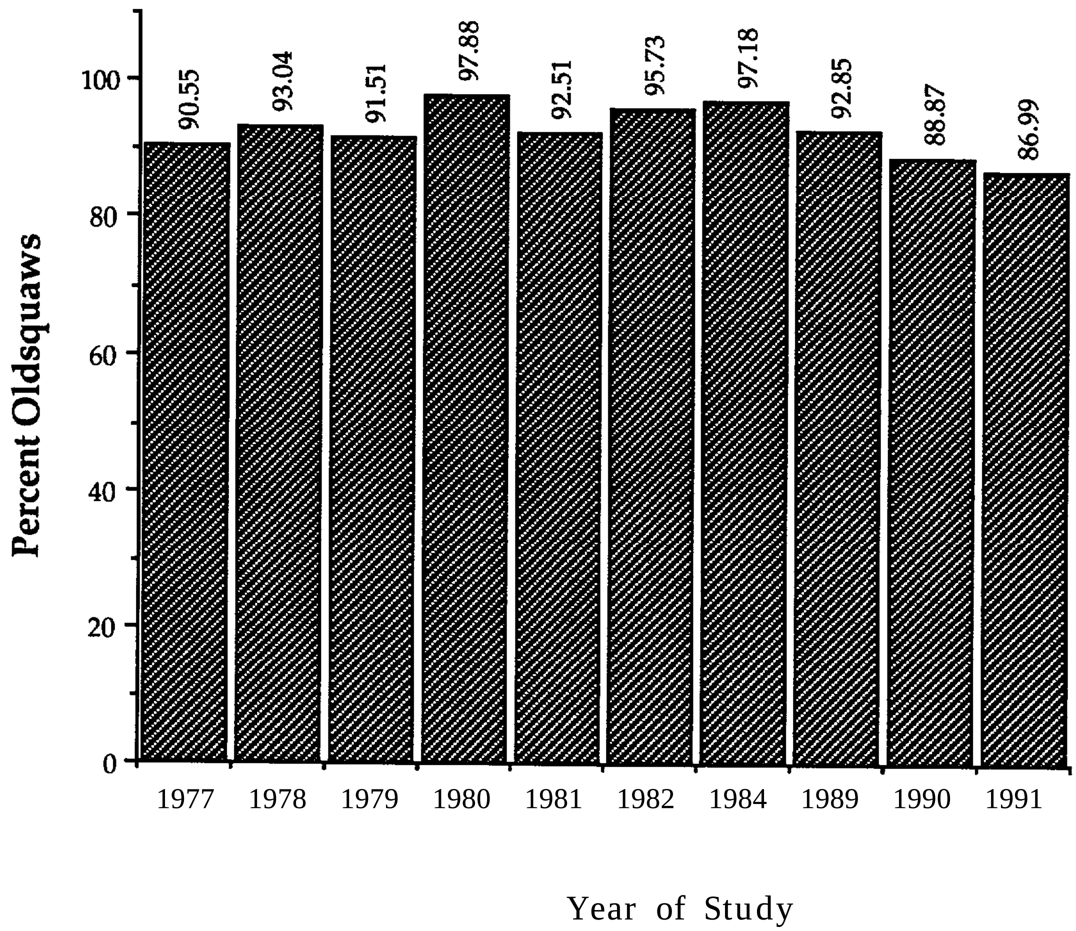


Figure 1. Oldsquaw sightings as a percentage of all waterbird sightingsin the central Alaska Beaufort Sea, 1977-1982, 1984, and 1989-1 991.

and early September; in years of bad production, there may be few. This is also true for eiders and brant.

Consequently, although these species are often detected and recorded during ground and air based investigations, their numbers can be highly variable, reflecting aspects of their life history not associated with activities in coastal barrier island-lagoon and nearshore habitats.

On the other hand, tens of thousands to hundreds of thousands of molting male oldsquaws use lagoon and nearshore habitats along the Beaufort Sea coast during mid-July through late August or early September, regardless of high or low production of young in tundra habitats. They congregate at locations where there is protection from wind, waves and moving ice and where there is abundant food to support them while they replace virtually their entire plumage. During this molt period oldsquaws are flightless for nearly a month (Johnson 1982a,b; 1983; 1984a,b; 1985). Thus, oldsquaws are relatively sedentary during the July-August peak of the molt period, and are relatively easy to count at this time. OCS-related activities in nearshore environments are more likely to affect, in a consistent and measurable manner, the local and general distribution and abundance of oldsquaws than of the other species mentioned above.

In a monitoring program such as this one, it is essential to focus on the species that offer the best chance of detecting changes related to development in the area of interest. Such species should be present in the areas of concern for a reasonable period of time, should be abundant and widespread, and should be relatively easy to count reliably.

Furthermore, the biology of the focal species should be well enough understood to allow separation of natural variability in numbers and distribution from man-caused variability. There are few species in the nearshore Beaufort Sea that fit these criteria. The prime candidates are (1) oldsquaws in most nearshore habitats during July and August, (2) the phalaropes along barrier island beaches during a 10 to 20 day period in August, and (3) glaucous gulls primarily along barrier island beaches during mid-August through mid-September (Johnson and Richardson 1981). Only the oldsquaw is present in sufficient numbers in most nearshore habitats throughout the study area for a period long enough to be sufficient for monitoring.

Research Hypotheses

A monitoring program that is designed to detect the influences of industry activities on nearby birds must test specific hypotheses that relate to (1) the birds chosen to be monitored, and (2) the types of industry activities in the study area. The following null hypotheses were constructed with such factors in mind:

> HOI: There will be no detectable change in relative densities of molting male oldsquaws in selected Beaufort Sea index areas.
>
> H_o2: Changes in male oldsquaw distribution patterns are not related to OCS oil and gas development activity.

Hypothesis (1) relates to the possibility of a large-scale and long-term change in relative densities in Industrial vs. Control study areas. Hypothesis (2) concerns relationships between oldsquaw densities and short-term localized variations in human disturbance. These two hypotheses, as presented by LGL at the Beaufort Sea monitoring workshop (Dames and Moore 1984), were constructed after six years of aerial surveys and supplemental research on the distribution, abundance and behavior of marine waterfowl, mainly oldsquaws, in the Jones-Return islands area of the Alaska Beaufort Sea, During this period, aerial survey procedures were modified to improve the distribution and resolution of sampling, and the surveys were continued through 1984, thus establishing a 7-year base of useful information on the distribution and abundance of oldsquaws (primarily molting males) in and adjacent to the Jones-Return islands area.

At the start of this study we adopted the above two null hypotheses as our working hypotheses, and we outlined an approach to test the hypotheses by developing and testing a monitoring protocol that was based on a series of low-level aerial surveys of oldsquaws (Johnson 1990). The design took into account all historical information and was based on the premise that there are several complex and interactive natural variables (i.e., migration schedules of birds, time of year, time of day, wind speed and direction, presence or absence of a barrier island nearby, distribution of ice, wave height, etc.) that significantly influence the behavior of these birds, and therefore significantly influence the results of aerial surveys of them in the nearshore Beaufort Sea area.

The specific objectives of the design phase of this project were to (1) conduct another year of surveys (1989) using procedures tentatively planned for monitoring, (2) analyze existing historical data (including 1989) to assess factors to be taken into account for the monitoring program, and (3) design the monitoring approach to be used in following years (i.e., 1990 and 1991).

The full-scale monitoring program was tested in 1990 and 1991. Systematic aerial surveys were conducted along established transects in different habitats in the Industrial and Control study areas in both years. This type of experimental design, involving a series of replicate surveys of an experimental and control area over several years before and after human perturbations, is consistent with procedures recommended by Green (1979) and Underwood (1991) for detecting human environmental impacts in natural populations. The following sections describe (1) the most important details of the originally proposed monitoring protocol (from Johnson 1990), and (2) results and recommendations arising from the testing phase of the study.

DEVELOPMENT OF A MONITORING PROTOCOL

Studv Areas

The Tones-Return Islands Industrial Area

The terms-of-reference identified the Jones-Return island chain, west of Prudhoe Bay, Alaska, as the Industrial study area for this study (Figs. 2 and 3). These islands have remained relatively undeveloped over the past two decades although there has been significant oil and gas exploration and development on the adjacent mainland tundra.

The Stockton-Maguire-Flaxman Islands Control Area

The Stockton-Maguire-Flaxman islands area (Figs. 2 and 4), located about 50 km east of the Industrial area, was selected as the Control area for the present monitoring study. The area is similar in structure and size to the Industrial area, it is used extensively by oldsquaws and other waterbirds, and there was a base of historical aerial survey data for use in statistical analyses and comparisons.

The Control area is situated along a part of the Beaufort Sea coast where very little coastal or nearshore industrial activity has occurred. Although several oil wells have been drilled during winter on or adjacent to a few of the islands in the Control area (e.g., Challenge Island), and on the adjacent mainland tundra (e.g., Pt. Thompson), the area is relatively pristine and undisturbed compared to the Industrial study area.

Retrospective Assessment of Variables Affecting Oldsquaw Densities

Several important and relatively well understood variables were thought to influence the number of oldsquaws present in the two study areas. Based on the results of earlier studies, we selected relevant predictor variables for use in a multiple regression analysis which allowed us to determine quantitatively which variables were most closely related to the densities of oldsquaws recorded on aerial survey transects during 1977 through 1989.

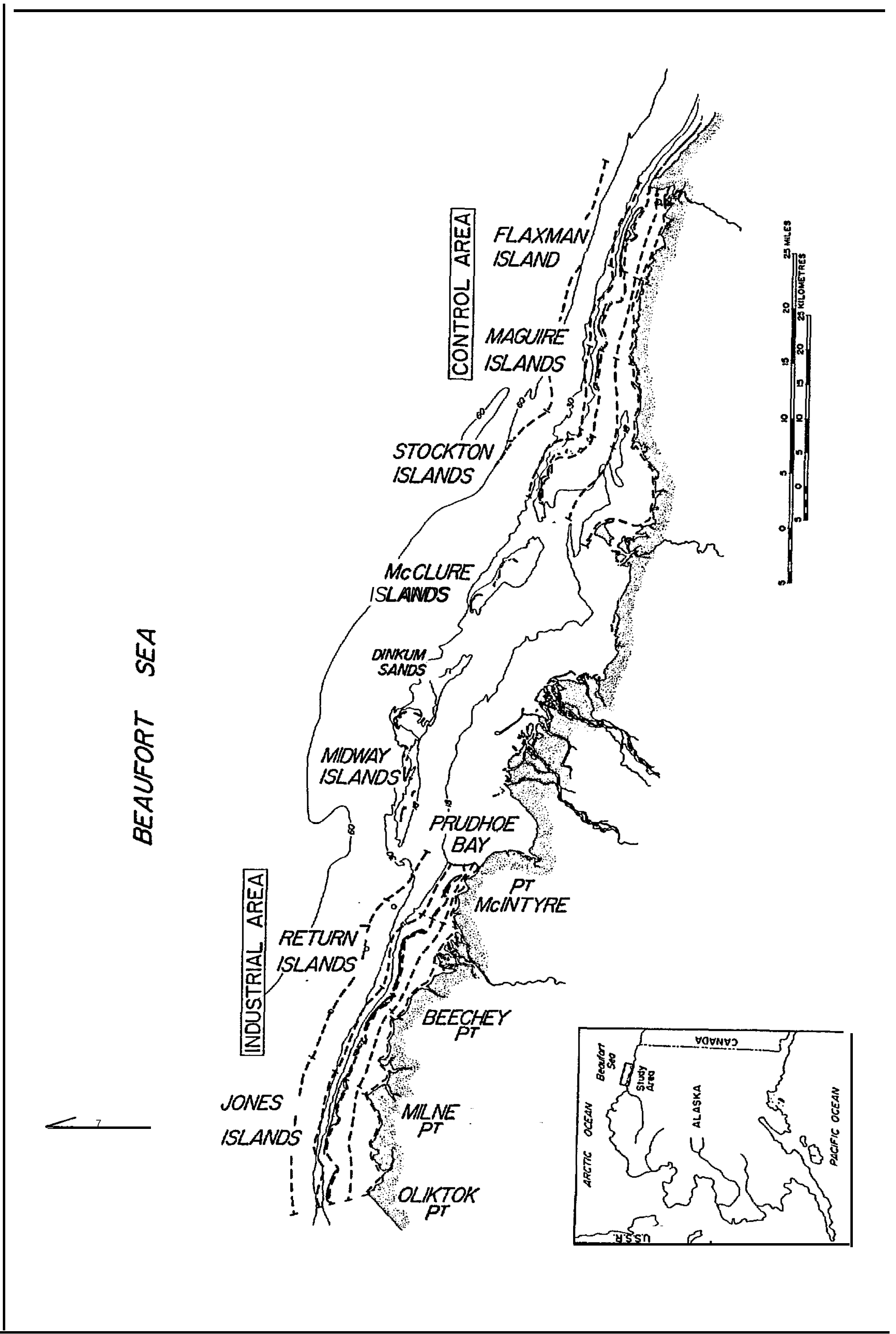


Figure 2. Central Alaska Beaufort Sea with Industrial and Control study areas.

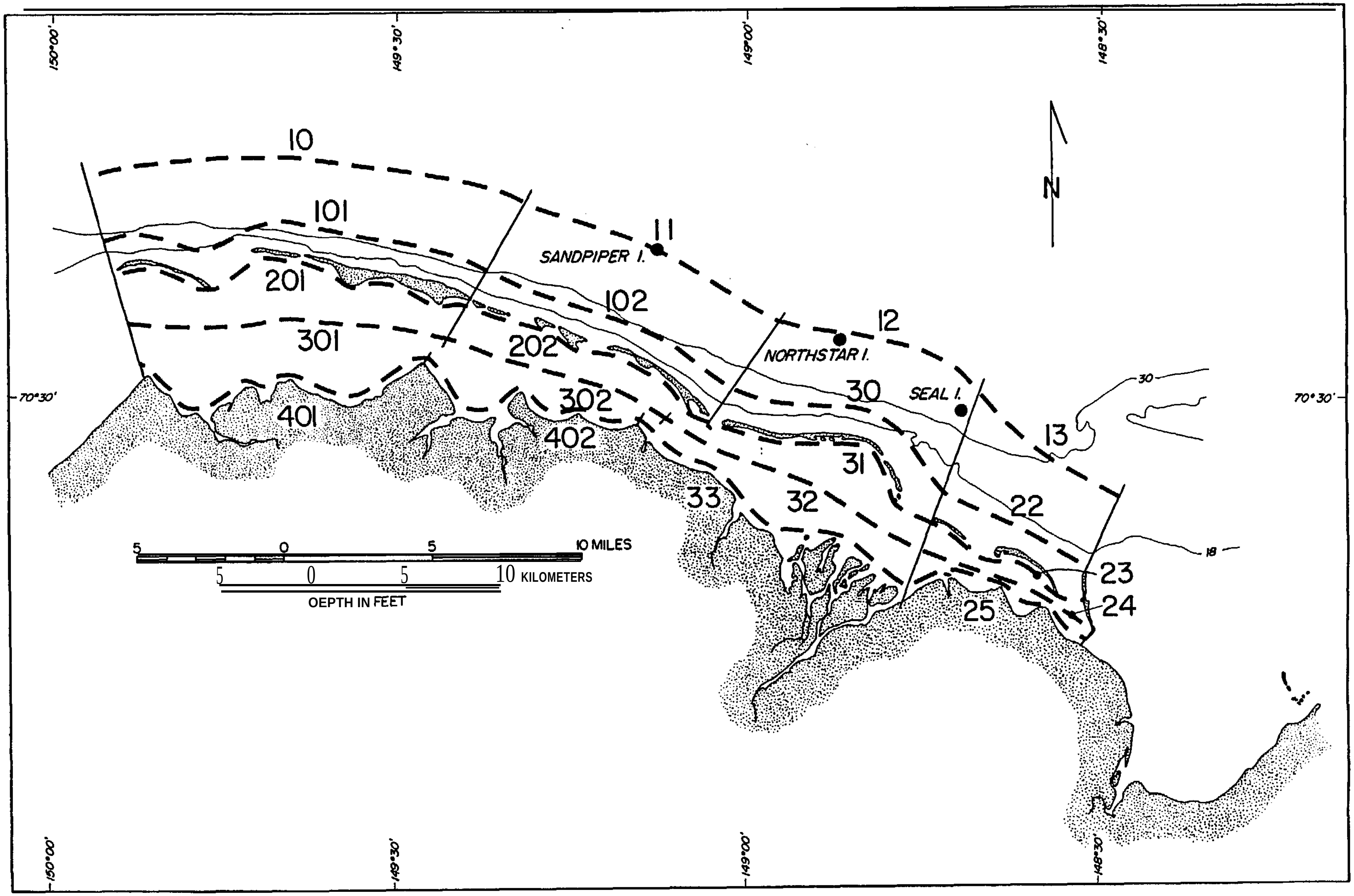


Figure 3. Industrial study area in the Jones-Return islands area, central Alaska Beaufort Sea. The West Dock (ARCO) Causeway is at the far easternendsof transects 23 through 25.

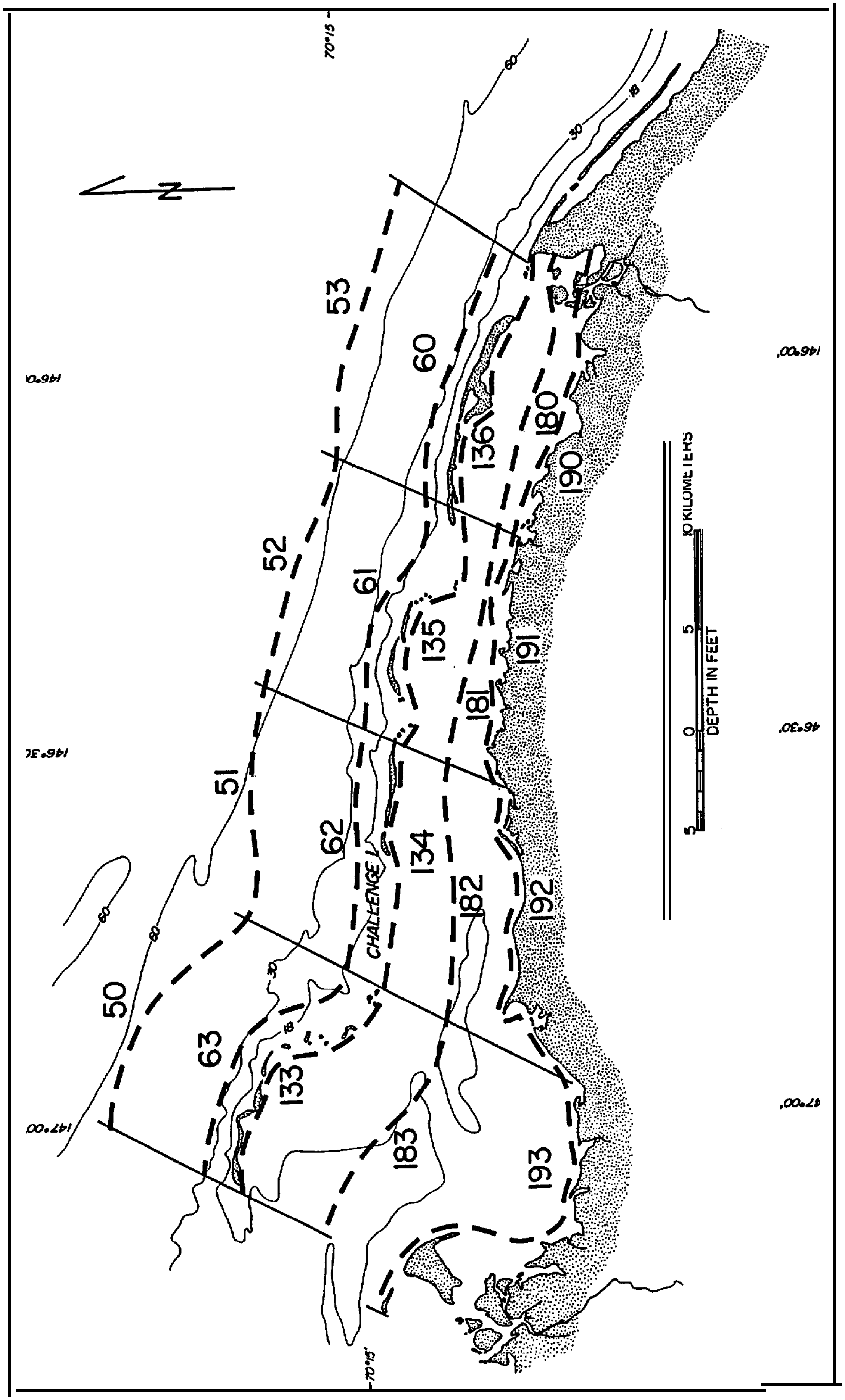


Figure 4. Control study area in the Stockton-Maguire-Flaxman islands area, central Alaska Beaufort Sea.

Each of the relevant predictor variables (independent variables) selected for use in the multiple regression analysis of oldsquaw density on transects in the study areas is discussed below, and a brief rationale is given for its inclusion in the analyses.

1. Year of study. Earlier studies (Johnson and Richardson 1981) and subsequent analyses in this study (Append. 1) have shown that densities of oldsquaws on specific transects in the Jones-Return islands area varied considerably from one year to the next. Consequently we included a YEAR term in the analyses to test for a long-term linear trend.

2. Time of the year (day of the season) that sampling occurred. Previous studies clearly showed that use of nearshore habitats by oldsquaws and other marine birds was highest during the summer open water period (Johnson and Richardson 1981). Numbers and densities were consistently high during the month-long period from mid-July to mid- to late August when male oldsquaws congregated in nearshore lagoons to molt (Johnson 1985:Fig. 6; Garner and Reynolds 1986:129). Consequently we included a DAY term in the multiple regression analyses. A second order term (DAY^2 = DAYTRAN) was also included to allow for a possible non-linear relationship to this variable.

3. Time of day that sampling occurred. Long-term, continuous observations in the Jones-Return island area showed that in undisturbed situations molting oldsquaws exhibited a 24-hr cycle of distribution, abundance and behavior in barrier island-lagoon habitats (Johnson 1982, 1983, 1985) (Fig. 5). We included TIME and $TIME^2$ terms in the analysis.

4. Water depth in the sampling area. Studies of prey density and feeding behavior of oldsquaws in the Jones-Return islands area indicated that they fed preferentially in the shallow nearshore lagoons. These studies also showed that the invertebrate prey of oldsquaws was most abundant in the deeper parts (2-3 m) of the lagoons, and that oldsquaws fed more efficiently (had more food in their stomachs) in areas of the lagoon where invertebrates were abundant (Johnson 1984a; Griffiths and Dillinger 1981) (Table 1). Thus, a water DEPTH term was included in the multivariate analysis.

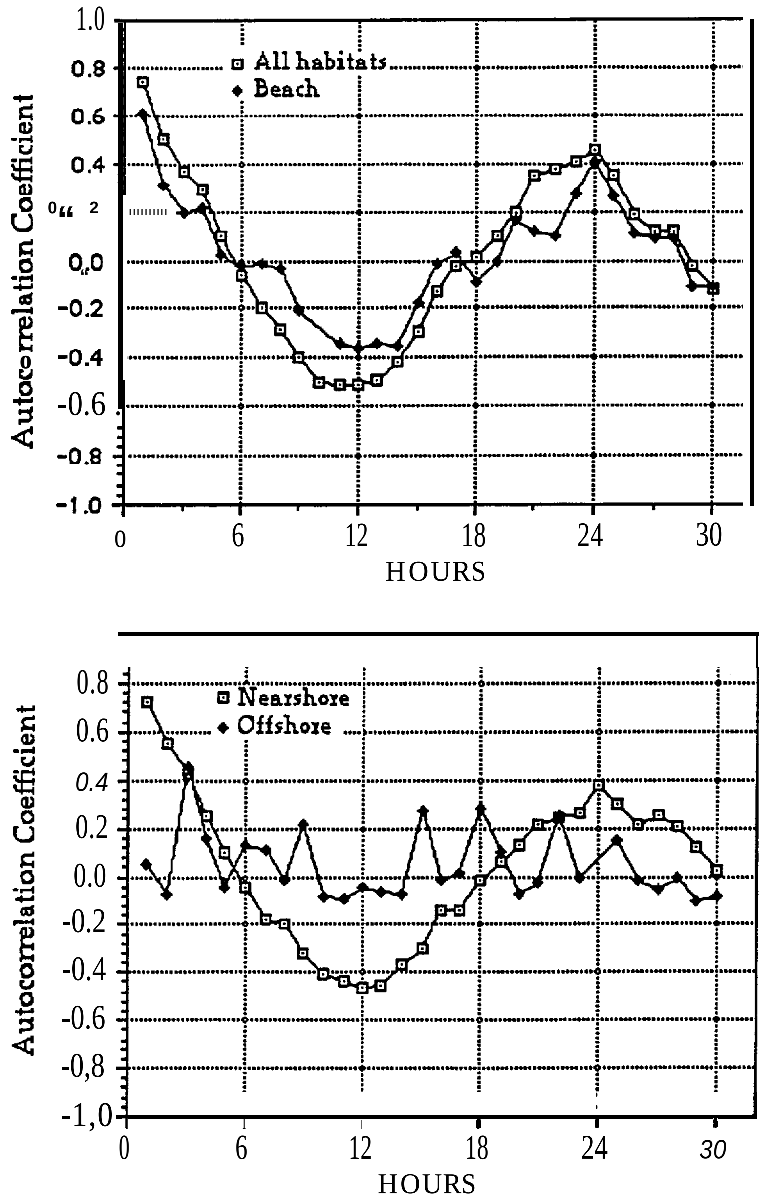


Figure 5. Results of autocorrelation analyses of numbers of oldsquaws in various barrier island-lagoon habitats during four 30-hr cycles (120 hrs) of activity when oldsquaws were relatively undisturbed and when waters were calm. Lag (hour) correlations of numbers of oldsquaws in beach, nearshore and total lagoon habitats showed a 24-hr period; numbers in offshore habitats showed little periodicity (from Johnson 1982a).

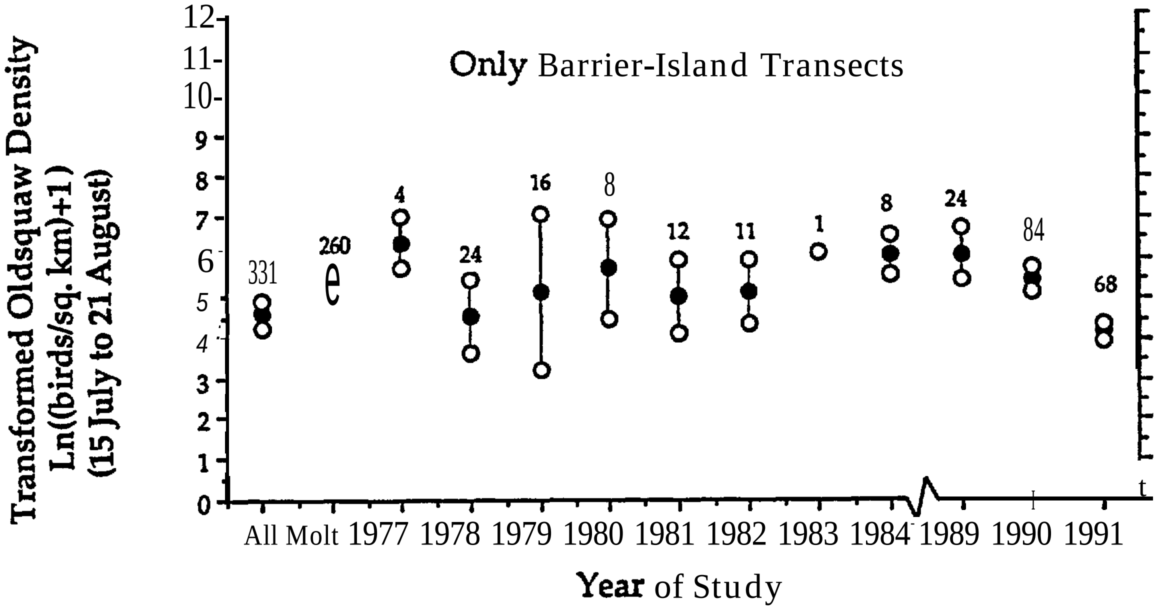
Table 1. Summary of water depths and feeding efficiencies of oldsquaws in the Jones-Return islands area, Beaufort Sea, Alaska (Johnson 1984a).

		1977	1978	
		All Oldsquaws (n=77)	Feeding Oldsquaws (n=81)	All Oldsquaws (n=108)
Water Depth (m)		2.09±0.178	2.07±0.179	2.05±0.172
Spearman Correlation of prey in Stomach vs. prey in Habitat (g. dry wt.)		All Inverts.	Mysids	Amphipods
	Spearman r	0.68	0.34	0.02
	p	<0.001	0.02	0.1
	n	25	25	25

5. Location of the sampling area along an east-west axis. Although oldsquaws congregate in barrier island-lagoon habitats along the entire Beaufort Sea coast where suitable habitat exists, earlier studies showed that densities of oldsquaws were consistently higher in some parts of the study area compared to others (Johnson and Richardson 1981; Johnson 1984b; Garner and Reynolds 1986). As a consequence, we subdivided the coastline, including the two study areas, into 12 west-east subdivisions (1 = transects at the far western end of the Industrial area, and 12 = transects at the far east end of the Control area), and included a WESTEAST term in our analyses.

6. Proximity of sampling area (transect) to a barrier island. Earlier studies, and preliminary analysis of data in the present study, indicated that the numbers and densities of oldsquaws and other waterbirds were generally greater on transects close to barrier islands compared to other transects more distant from barrier islands (Fig. 6)(Johnson 1985; Johnson and Richardson 1981; Brackney et al. 1985:350). It was not surprising that 95% confidence limits of means were generally lower during years when large numbers of transects were sampled (i.e., 1989-1990, Fig. 6). Two predictor variables included in our analyses relate to proximity of the sampling area to a barrier island. One measure (DIST) is the absolute value (on a continuous scale) of the average distance of the transect from the nearest barrier island.

The other measure (HABITAT) is composed of five categories of habitats: Habitat 1 is immediately lagoonward of the barrier islands; Habitat 2 is mid-lagoon; Habitat 3 is immediately lagoonward of the mainland shoreline; Habitat 4 is 1.5 km seaward of the barrier islands; Habitat 5 is 5 km seaward of the barrier islands (Figs. 2 and 3). In the multivariate analysis HABITAT was a categorical variable represented by a set of four dummy variables (see Wilkinson 1987; Draper and Smith 1981). Habitat 1 was the standard against which others were compared; analysis results were combined into a single F-ratio (with 4 d.f. rather than the usual 1 d. f.) reflecting the overall effect of habitat on oldsquaw density. The HABITAT, DEPTH (water depth), and DIST (distance of transect from the barrier island chain) variables were interrelated, and the final regression analyses included only the single categorical variable HABITAT.



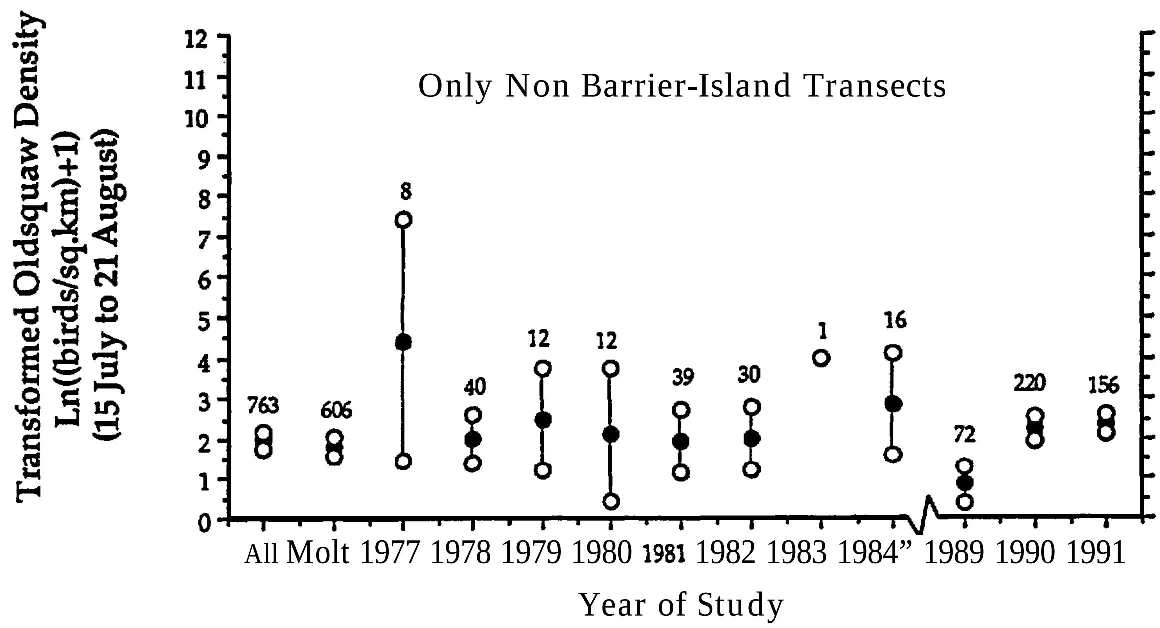


Figure 6. Mean ± 95% C.I. (confidence intervals) of transformed densities [ln(l+density)] of oldsquaws on all barrier island transects (Habitat 1) and non-barrier island transects (Habitats 2-5) during the molt period (15 July-21 August) in the central Alaska Beaufort Sea, 1977-1984, and 1989-1991. Also shown, at left, are values for all years combined during (A) all survey periods (5 June to 23 September), and (B) during the molt period alone. Sample sizes (numbers of transects) are given for each set of surveys.

7. Wind speed and direction in the sampling area during the sampling period. Prevailing winds in the central Beaufort Sea during the summer are northeasterly or northerly (Brewer et al. 1977). Earlier studies indicated that oldsquaw densities on different transects in the Jones-Return island area are significantly related to the speed and direction of wind during aerial and ground-based sampling (Johnson and Richardson 1981). Wind speed (WSPD) was measured in km/hr, and wind direction was measured on several scales – a 360° scale (WDIR = cosWDIR), and on an ordinal octant scale (ORDWND). Two other continuous measures of wind speed and direction were included as predictor variables, the northern component (NCOMWND = wspd x cos(wdir)) and northeastern component (NE C O M W N D = wspd x cos(wdir+45)) of the wind. Since all of these variables overlapped to some extent, we used only wind speed (WSPD) and transformed wind direction (cosine of degrees = WDIR) in the final analyses.

8. Percent ice-cover on-transect in the study area during the sampling period. Earlier studies indicated that densities of oldsquaws during the male molt period in the Jones-Return islands area were higher in lagoon habitats where there was consistently less ice on-transect than in areas seaward of the barrier islands (Johnson and Richardson 1981). Consequently, we included the estimated percent ice cover on-transect (LN of percent ice = ICE) as a predictor variable in the multiple regression analysis.

9. Wave height on-transect in the study area during the sampling period. Wave height on transects in the sampling area is directly related to the direction and speed of wind, which were discussed previously as separate predictor variables. But wave height also has a significant influence on the detectability of oldsquaws and other marine birds swimming on the water, and thus affects the apparent density of oldsquaws recorded on-transect. Wave height is a standard measurement recorded during LGL's aerial surveys; consequently we included it as a separate predictor variable (WAVEHT) in our analyses.

10. Study Area. There are two distinct sampling areas in this study (Industrial and Control areas). As a result, analyses included a single dummy variable (Wilkinson 1987; Draper and Smith 1981) reflecting the overall effect of the particular study area within which the transect is located.

Results of Multiple Regression Analyses

Two separate multiple regression analyses were conducted on the 1977-1984 and 89 data (Table 2). One analysis considered the complete study period using all available data for all transects surveyed on any date (5 June to 23 September) during all years of study (1977 to 1984, and 1989). Only complete sets of data, i.e., no missing variables, were used for this analysis. A similar analysis was done using data only from the oldsquaw molt period (15 July to about 15 to 20 August) during all years of study. Each survey of each transect constituted a unit of observation.

The multiple regression analysis for all dates and years (complete study period) showed a relatively strong relationship between the predictor variables and the density of oldsquaws (n = 474 transects, multiple R = 0.76) (Append. 2); several of the predictor variables were nominally significant as predictors of the dependent variable DENSTRAN. About half (multiple R^2 = 0.57) of the variation in oldsquaw density for the complete open-water period was accounted for by the predictor variables and interaction terms used in this multiple regression analysis (Table 2).

Results of the multiple regression analysis of data from the oldsquaw molt period (15 July-20 August) were very similar to those from the overall study period. There were strong relationships between several of the predictor variables and the density of oldsquaws (n = 275 transects, multiple R = 0.83) (Append. 3). About two-thirds (multiple R^2 = 0.68) of the total variation in oldsquaw density was accounted for by the variables and interaction terms used in the present multiple regression analysis.

Wave height, habitat type, day of year, day of year x habitat interactions, time of day x habitat interactions, and ice cover x habitat interactions all were important (and statistically significant) variables that helped predict oldsquaw density in the study areas. Analysis of residuals helped determine whether necessary assumptions of multiple regression analysis were met (normally distributed residuals, appropriate transformation of data, homogeneity of variance, linearity of relationships, etc.) (Append. 4).

Table 2. Summary of results of multiple regression analyses of historical oldsquaw density data collected in the Jones-Return islands area, Beaufort Sea, Alaska, during 1977 to 1984 and 1989'.

Independent Variables	Degrees of Freedom	5 June to 23 September (Squared Multiple R = 0.574, n =474)			15 July to 15 August (Squared Multiple R= 0.6S1, n = 275)		
		Coefficients	F-Ratios	Nominal P Values	Coefficients	F-Ratios	Nominal P Values
CONSTANT	N/A	-2.179	N/A	N/A	-1.269	N/A	N/A
YEAR	1	-0.038	1.30	0.256	-0.076	3.30	0.070
DAY	1	0.097	19.62	***≤0.001*****	0.099	0.17	0.678
DAYTRAN	1	-0.001	0.15	0.702	-0.001	0.08	0.774
TIME	1	0.001	1.02	0.314	0.001	1.34	0.248
WESTEAST	1	4.054	0.52	0.474	-0.128	1.89	0.170
WSPD	1	0.003	0.00	0.965	-0.025	0.17	0.680
WDIR	1	-0.003	0.83	0.362	-0.007	2.86	0.092
WDIR*WSPD	1	0.000	1.68	0.196	0.000	7.44	***0.007*****
ICETRAN	1	-0.047	0.11	0.745	0.374	1.51	0.220
WAVETRAN	1	-0.376	6.81	0009”’	-0.457	6.63	0.021**
HABITAT(1-5)***	4	-0.229; 3.911; -4.105; 1.513	4.22	***0.002*****	-1.645; 3.244; 2.415; 3.25B	1.58	0.180
AREA	1	-0.010	0.00	0.989	-1.121	1.38	0.241
YEAR*AREA	1	0.016	0.12	0.732	0.153	7.36	***0.007*****
HABITAT(1-5)*DAYTRAN	4	-0.000; 0.000; 0.000; 0.000	2.38	0.051	0.000; 0.000; -0.000; -0.001	1.20	0.310
HABITAT(1-5)*TIME	4	0.002; -0.003; 0.002; -0.002	13.62	*<0.001 ***	0.002; 4.003; 0.001; -0.000	7.34	***< 0.001*****
HABITAT(1-5)*WSPD	4	0.004; -0.006; 0.062; -0.044	2.01	0.093	0.003; 0.004; 0.034; -0.077	1.44	0.221
HABITAT(1-5)*WDIR	4	0.001; 0.000; -0.002; 0.004	0.91	0.457	0.003; 0.003; -0.002; 0.000	0.67	0.616
HABITAT(1-5)*WAVETRAN	4	0.227; 0.329; -0.754; 0.080	2.36	0.052	0.359; 0.198; -1.030; 0.210	1.16	0.329
HABITAT(1-5)*ICETRAN	4	-0.357; 0.001; -0.051; 0.119	2.32	0.057	-0.322; 1.181; 0.195; -0.892	3.66	***0.007*****

* See Appendices 2 and 3 for a complete listing of the regression models and analysis of variance tables.

** Nominal P values ≤ 0.050 were considered to be statistically significant.

*** Habitats are as follows 1 = S of barrier islands, 2 = mid-lagoon, 3= mainland shoreline, 4 = nearshore marine, and 5 = offshore marine. Habitat 1 is omitted because it is the 'standard' against which others were compared in this analysis.

Influences That May Affect Oldsquaw Density

The overall proportions of variation explained by the predictor variables in the two multiple regression analyses (R^2) were about 0.57 for the complete study period, and 0.68 for the molt period. These values, although somewhat less than hoped for, are better than might be expected considering that field data collected for purposes other than long-term monitoring were analyzed retrospectively. Nevertheless, the R^2 values were substantially less than 1.0, indicating that factors other than those allowed for in the regression models were affecting oldsquaw distribution, abundance and density. These additional factors probably included (a) natural variability in waterfowl behavior, (b) measurement error, and (c) unmeasured variables (inside and outside the study area).

Measurement error is an unavoidable component in many of the variables used in this study, especially environmental variables such as amount of ice, wave height, wind direction and speed, etc., estimated on-transect during the course of aerial surveys. This type of error is somewhat reduced when experienced observers conduct aerial surveys, but some measurement error is inherent in any sampling program, especially one conducted from a fast-moving aircraft flying at low level.

A shortcoming of earlier aerial surveys was that there was no record of the level of human activity and disturbance on transects, aside from the obvious, but often unrecorded, presence or absence of a major structure, such as an artificial island, causeway, or drilling structure.

Another major confounding factor is the degree to which the distribution and abundance of oldsquaws may be determined by influences outside the study area, and therefore not measurable in a local or regional monitoring program such as this one. This potential source of variation may have a significant influence on the distribution, estimated abundance, and density of oldsquaws in both study areas. Most waterfowl are highly traditional in their behavior, e.g., they often nest, molt, migrate and over-winter in the same general area from one year to the next (Hochbaum 1955; Lokemoen et al. 1990). There is uncertainty, however, about whether oldsquaws occupy the same barrier island-lagoon systems from one year to the next, or about the degree of movement of birds from one nearshore area to the next. Radio telemetry studies of oldsquaw movements in barrier island-lagoon habitats in the Arctic National Wildlife Refuge, Alaska, showed that molting oldsquaws moved an average distance of 0.69 km / day& s.d. 1.29, and ranged from 0.01 to 3.85 km / day (Brackney et al. 1985). All movements of these radio-tagged oldsquaws were local and within or adjacent to the lagoon in which the birds were originally captured.

Nevertheless, the 500 km long chain of barrier islands, lagoons, bays and large freshwater lakes along the Beaufort Sea coast from Point Barrow, Alaska, to Cape Parry, NWT, Canada, are all used by marine waterfowl, especially oldsquaws, but also by smaller numbers of scoters (*Melanitta* spp.), red-breasted mergansers (*Mergus serrator*), and Pacific eiders during the post-breeding molt period. There is little or no information that describes how various environmental and biological factors interact to determine which areas may be used by molting oldsquaws from one year to the next. The molt migration by oldsquaws is generally westward along the Beaufort Sea coast in late June through mid-July (Johnson and Richardson 1982). Influences such as (1) amount of ice present and timing of ice break-up in a particular barrier island-lagoon system, (2) oceanographic conditions along one part of the coast in relation to another, and (3) weather during the molt migration (e.g., presence of favoring tailwinds versus headwinds), may all influence whether some or all birds from one particular area may be attracted to a lagoon during the molt period. The scale of such events is too large to be accounted for in a monitoring program conducted along only one part of the Beaufort Sea coast; a coast-wide study would be necessary to determine if there are large-scale changes in abundance of oldsquaws (or any other of the widely distributed species) in one part of the Beaufort Sea relative to another.

We suspect that such factors not included in the regression analyses may have had a significant influence on the numbers and densities of oldsquaws recorded during past years in central Beaufort Sea barrier island-lagoon systems. Although some of these influences would be difficult (if not impossible) to measure, it was thought to be possible to design a monitoring program so that much of the remaining variability could be accounted for. The proposed implementation plan for such a program is described below.

Proposed Implementation of a Monitoring Protocol

Desire Considerations

Results from earlier studies (Johnson and Richardson 1981; Troy and Johnson 1982), and from the multivariate analyses described above, have indicated that some of the variation in apparent oldsquaw density is attributable to sighting conditions, as influenced by wind, sea state, ice cover, sun glare, etc. Additional variation may be attributable to local variations in human activities and disturbance within the areas designated as either Industrial or Control. It is important to account for the causes of as much of this variation as possible in order to maximize the power of the statistical procedures to identify the presence and magnitude of any industrial effects, either broad-scale (i.e., Industrial Area vs. Control Area) or fine-scale (transect-to-transect within one or both study areas). Consequently, in future analyses associated with the Beaufort Waterbird Monitoring Protocol, one or more additional independent variables that were which have been absent from all earlier analyses need to be included. One variable should be "Level and type of industrial activity on or near the transect during an aerial survey." We categorized these activities into five levels of possible disturbance (Table 3); a value is assigned separately to each transect on each survey date.

R was also thought that additional meteorological and oceanographic factors could influence the distribution, abundance, and movements of oldsquaw ducks. Factors such as seasonal upwelling potential and/or seasonal mean wind speed and direction (Craig et al. 1984; LGL 1990a,b; LGL et al. 1990a,b), which are known to influence the distribution, abundance and movements of invertebrates and anadromous fish in the nearshore Beaufort, may also need to be considered in the interpretation of oldsquaw data in future analyses.

Table 3. Ordinal scale for recording types of industry activities and disturbance levels that may affect oldsquaw densities in the Jones-Return islands, Beaufort Sea, Alaska. Values are assigned separately for each transect during each survey date.

Activity Index	Disturbance Level	Type of Industry Activity
1	Nil	No human activity or disturbance in area of interest.
2	Low	Infrequent low-level aircraft overflights, boat traffic or human activity on land or in the water during the survey period in the area of interest.
3	Moderate	Regular** low-level aircraft overflights, boat traffic or human activity on land or in the water during the survey period in the area of interest.
4	High	Frequent† low-level aircraft overflights, boat traffic or human activity, and/or spillage of low levels of toxic materials (oil, fuel) and associated clean-up activities on land or in the water during the survey period in the area of interest, and/or semi-permanent structures established in the area with frequent presence of humans and associated activity.
5	Extreme	Major spill of toxic materials (oil, fuel) and associated clean-up activities on land or in the water during the survey period affecting a large area, including the area of interest, and/or permanent structures established in the area with near-continuous presence of humans and associated activity.

* Less than five known occurrences during the 24-h survey period. Low-level overflights 500’ altitude.
** Five to nine known occurrences during the 24-h survey period.
† Tenor more known occurrences during the 24-h survey period.

Sampling Procedures

It was clear that the need for powerful analytical approaches in the monitoring program would necessitate the use of field sampling procedures that would satisfy the requirements of those analysis methods. We planned the 1990 and 1991 sampling in such a way as to obtain data for the following spatial and temporal categories:

Two study areas (Industrial and Control).

Five habitat strata characterized by proximity of the sampling area to barrier islands (e.g., 0.40 km south of barrier islands, 0.41 -1.61 km south and north of barrier islands, and 1.62 km -4.83 km south and north of barrier islands). These distances are equivalent to (1) barrier island habitat (within 0.40 S of barrier islands), (2) mid-lagoon habitat (variable distances S of barrier islands), (3) mainland shoreline habitat (variable distances S of barrier islands), (4) inshore marine habitat (1.5 km north of the barrier islands), and (5) offshore marine habitat (5 km north of the barrier islands).

Four contiguous (end-to-end) transects within each habitat stratum and study area.

Four 5- to 7-day sampling periods during each year.

Three survey dates within each 5- to 7-day sampling period.

It was thought that this sampling hierarchy would provide the replicated and structured data necessary to isolate the effects of the variables known to affect bird densities. This experimental design was compatible with the powerful ANOVA and ANCOVA statistical procedures that we proposed to use to separate the effects of year, date, time, east-west location, study area, habitat, amount of ice, wind, wave height, and level of disturbance, etc.

Although our original proposal did not recommend that mainland shoreline habitats be sampled as part of the proposed monitoring, we later — after the retrospective analyses were done — recommended that, within each of the study areas, a habitat stratum along the mainland shoreline be added to the monitoring protocol. Relatively large numbers of oldsquaws (and other marine birds) use mainland shoreline habitats sporadically during the proposed sampling period, especially in the Control study area where various small lagoons and spits along the mainland coast provide suitable sheltered habitats for oldsquaws. Furthermore, birds in these mainland coastal areas could well be the first to be affected by industrial activities; development probably will occur along mainland shorelines areas before it does so on the adjacent barrier islands. Also, changes in density along the mainland shore may be important in understanding simultaneous changes in numbers in other habitats.

Schedule of Surveys

Based on the results of earlier studies and on the results of the regression analyses described above, the appropriate period for surveys of marine birds in both Beaufort study areas (Industrial and Control) was from mid-July until late August or early September, i.e., during the oldsquaw molt period. Surveys during this period would sample only flightless male oldsquaws. We recommended that four survey periods be scheduled during the molting season at about 8-10 day intervals, starting on or about about 15 July. All transects were to be surveyed three times during each of four 5- to 7-day survey periods. These repeated measurements were to provide the three replicate surveys during each sampling period that are needed for variance computations for each period.

We also recommended that surveys be conducted as quickly as reasonable, and that they not be conducted during periods or in areas of high winds (>20 kts.) and heavy ice (>30 % cover). Since we recommended that surveys start on 15 July, after ice break-up has usually occurred in the marine system, heavy ice-cover would be less of a problem in the future than during some previous years when some surveys began as early as 5 June. Beaufort Sea lagoons are usually ice-free by mid-June. During some years, however (e.g., 1974 and 1975), ice and associated fog persist in nearshore and offshore marine regions of the Beaufort Sea throughout the summer. In such years we recommended that only barrier island and lagoon transects be surveyed, so that at least those data would be comparable from one year to the next.

Data Recording

It was recommended that recording of aerial survey data be standardized according to procedures established during a set of structured surveys conducted in early August 1989. During those surveys we adopted 30-sec time-period intervals for recording the numbers of birds on- and off-transect and for recording an array of information about the survey conditions and prevailing environmental conditions. For each 30-sec interval, factors recorded included amount of ice on- and off-transect, wave height, glare on the water surface, wind speed and direction, proximity to barrier island or other structure, apparent type and level of human activity on- and off-transect during the time period, and changes in any particular variable noted during that 30-sec interval. The 30-sec periods have been used in most waterbird surveys in the study area since 1980; compared to 1- or 2-min intervals, they provide better documentation of locations where birds concentrate and where habitats change along transects. Consequently data collected at 30-sec intervals are more useful than data collected by longer intervals, especially if they might be mapped or included at a later date in a database or in a Geographic Information System (GIS). It was recommended that information be collected for all speaes of birds and mammals observed on and off the transects.

Surveys are flown with two prime observers at an altitude of 45 m and at a ground speed of 180 km/hr. Transect width is 400 m, 200 m on each side of the aircraft; clinometers are used to calibrate distances from the aircraft. Observers are trained to count large numbers of birds in dense concentrations through a series of poppy-seed trials. Varying quantities of poppy-seeds (or some other appropriately-sized granular material) are distributed on a sheet of paper by an independent examiner isolated from the observers. The observers are then allowed 5 seconds to estimate the number of seeds on the paper. The trial is repeated 5-10 times with different numbers and patterns of seeds. After the final trial, the scores of each observer are tallied and compared with the actual number of seeds using Chi-squared techniques (observed-expected). These trials help the observer to accurately estimate large numbers of birds in dense concentrations; furthermore, inherent biases in counting ability may also be detected and accounted for in corrected density computations. Computer programs are also available that assist in estimating numbers of objects below an aircraft (J. Hodges pers. comm.).

During aerial surveys, tape recorders are used to record information about the birds, their habitats and environmental conditions during the survey. Data are later transcribed and coded onto standard coding forms that provide for accurate recording of all of the information described above. Linear and areal densities are computed for all species sighted on-transect during all surveys; linear densities are also computed for on+off-transect sightings. These data are manually and computer verified, validated, and then computer tabulated by species, year, date, time-period, transect, and observer.

Analysis Procedures

The multiple regression approach described in the preceding sections is optimum for examining historical data collected in a rather unstructured manner. However, greater statistical power and precision would be obtained by collecting future data in the more structured fashion summarized above. It was proposed that these data should be examined primarily by analysis of variance (ANOVA) and analysis of covariance (ANCOVA) methods.

In the design phase of this study, we identified many variables that should be taken into account in the analysis. These included variations in waterbird density attributable to sampling period, time of day, water depth, proximity to barrier island, east-west position within the study area, wind and ice conditions during surveys, local variations in human activity, etc. Because the proposed survey design was precisely structured with regard to year, study area, sampling period, habitat, and transect, these were identified as ***factors*** in an analysis of variance. Wind direction and speed, ice cover, wave height and other unpredictable continuously-distributed variables were best handled as ***covariates rather than as categorical factors.*** Measurements of human activity along each transect were a fifth ***covariate;*** by considering this variable, it was thought that we could assess the possibility of medium-scale industrial effects on waterbird density.

The **Proposed** ANCOVA Model

The ANCOVA model most appropriate to test for significant differences in oldsquaw densities over space and time would include — in addition to **covariates,** the following components:

Mean+A+Y+YA+H(A)+YH(A)+P(Y)+AP(Y)+T(H(A))+YT(H(A))+error,

where A = Area, Y = Year, H = Habitat, 1? = Periods, and T = Transects. Parentheses indicate that some factors are nested within others, e.g., H(A) is interpreted as habitat nested within area. An ANCOVA can be visualized as an ANOVA with the addition of covariates to help standardize the basic unit of analysis (oldsquaw density on a transect in a habitat in a study area during a survey in a sampling period within a year). The ANOVA model is nested (sampling period within year, habitat within study area, transect within habitat) and factor effects are mixed, i.e., some are fixed and some are random. Year, area and period are fixed and interpretations of analysis results of these factors can only be extended to the levels tested. On the other hand, habitat and transect were considered random effects since they could have been defined in a variety of different ways to represent the spatial structure of the factor.

The statistical significance of the year x area interaction, after allowance for other factors in the analysis, is to be the main test of the possibility of a large-scale industrial effect on oldsquaw density. This is one of the most important statistical tests in the monitoring protocol, and is directly relevant to the null hypotheses around which this study has been structured.

We recommended that the appropriate analysis of covariance (ANCOVA) procedures (see Bliss 1970; Huitema 1980) areas follows:

1. Log-transform the density data in order to reduce the skewness inherent in such data.
2. Conduct the ANCOVA with 5 covariates, including their 10 interaction terms with year and area. Covariate interactions with the finer scale temporal and spatial terms have been ignored since they are nested within year and area.

3. Non-significant interaction terms involving covariates should be removed sequentially in such a way that the term with the greatest p-value (least significant) is removed first; the ANCOVA model is then rerun and the remaining interaction terms are examined. This process is repeated until all statistically non-significant interaction terms have been removed.
4. Conduct the ANCOVA using the factors, covariates and interaction terms remaining after following the procedures outlined in 3. above. Also conduct an ANOVA (no covariates), and an ANCOVA with only the disturbance covariate so the overall effect of disturbance and the "environmental" covariates (wind, waves, ice, etc.) can be isolated.

The proposed three surveys of each transect during each sampling period in the field season provide the replication necessary for the ANCOVA. The ANCOVA identifies how much of the variation in densities of oldsquaws is attributable to each-factor, i.e., year, study area, sampling period, habitat and transect; and to each covariate, i.e., wind speed and direction, wave height, ice cover and disturbance. We developed an ordinal measurement of industrial activity (values 1 through 5) that could be assigned to each transect depending upon the type and amount of activity that was occurring in or immediately adjacent to the transect during the sampling period (Table 3).

Based on analyses of historical data and the preliminary test surveys conducted in 1989, we were confident that the monitoring plan presented above was the most appropriate and statistically powerful approach. This approach was to be tested in 1990, the second year of the present project, and the first full season of sampling. We also stated, however, that after one complete season of data collection (i.e., after 1990) and subsequent analyses, it might be necessary to modify some aspects of the field procedures or some of the analyses. Such modifications were to be documented and a rationale for changes in the protocol was to be provided.

Potential Problems and Sources of Error

The degree to which the various analysis assumptions are met in this study is important in determining whether the proposed analysis procedures are appropriate and statistically valid. The assumptions needed to conduct an ANCOVA such as the one recommended here are discussed by Huitema (1980), and are as follows:

1. Randomization, i.e., replicates are independent.
2. Homogeneity of within-group regressions, i.e., homogeneity of slopes in regressions of oldsquaw density versus covariates (between transects).
3. Linearity of within-group regressions, i.e., linearity of slopes in regressions of density versus covariates (between transects).
4. Statistical independence of covariate and treatment, i.e., covariates should not be correlated with treatment levels. Thus, wave height and ice cover, for example, should be unrelated to habitat, sampling period, etc.
5. Fixed covariate values that are known or measured without error.
6. Normality of conditional response scores, i.e., oldsquaw densities for each treatment are normally distributed after correction by the covariates.
7. Homogeneity of variance of conditional response scores, i.e., variation in oldsquaw densities is homogeneous for each treatment after correction by the covariates.
8. Clearly defined treatment levels.

Most of these assumptions were satisfied given the proposed structured experimental design. Several assumptions were problematic, however, and those are discussed below.

Repeated Surveys

One possible source of error that needed to be considered was that replicate surveys flown within a 5- to 7-day sampling period may not be independent of each other, i.e., the densities of oldsquaws seen on transects during one survey may be related to those recorded on the same transect during an earlier survey. The amount of day-to-day movement by oldsquaws from one transect or habitat to another is unknown; thus the actual amount of interdependency of oldsquaw densities on transects or habitats among surveys is unknown. One radio-telemetry study (Brackney et al. 1985) did show, however, that oldsquaws molting in barrier island-lagoon habitats in the Arctic National Wildlife Refuge (ANWR) moved as much as several km per day, with an average of about 0.7 km per day. Thus, it is possible that oldsquaws may move as much as 3 to 4 km or more within a 5- to 7-day survey period. Such movements indicate that oldsquaws may not remain on the same transect (or in the same habitat) for prolonged periods of time. Consequently, we have assumed that replicate surveys do provide independent samples of the populations of oldsquaws in the study areas.

As a possible alternative, we considered a Repeated Measures (RM) analysis as an alternative to the basic ANCOVA proposed above. RM allows for two or more non-independent surveys of the same area, and would thus seem to be appropriate in the present situation.

The RM model appropriate for this study would have the following basic structure, ignoring covariates:

Mean+A+Y+YA+H(A) +P(Y)+AP(Y)

A = Area

Y = Year

H(A) = Habitat nested within Area

P(Y) = Sampling Period nested within Year

This structure defines habitat within a year and area as the 'subject' which is measured by repeatedly sampling transects. Sampling is replicated each survey day.

A major shortcoming of the RM approach is the treatment of covariates. If covariates are measured for a 'subject', such as habitat within area, then the within-subject multivariate statistical tests are ***valid***. *If*, on the other hand, the covariates are measured at a lower level, such as transect within habitat within area, then the within-subject multivariate tests ***are not valid***. In other words, for this study, the test for H_o1 (year x area interaction) is valid regardless of the independence of the transect measurements or the treatment of covariates in the RM model. In contrast, the test for H_o2 (disturbance) is valid only if the measurements at each transect are independent. Considering these issues, we decided that the less restrictive ANOVA/ ANCOVA approach, as opposed to the RM approach, was most appropriate for this study.

Statistical Independence of Covariate and Treatment

It is probable that some covariates (e.g., wave height, wind speed and direction, amount of ice on-transect) depend on some treatment factors (e.g., habitat, study area). For example, offshore habitats may be more exposed to ice, and therefore transects in this habitat may have more ice than those sheltered by barrier islands. Similarly, transects in barrier island habitats may be sheltered from prevailing northerly winds, thereby affecting wave height in this habitat as compared to exposed offshore areas.

Such relationships between the treatments and covariates violate a fundamental assumption of ANCOVA. We have attempted to alleviate this problem by recommending that surveys should not be conducted (or transect densities should not be included in analyses) when extensive ice may be encountered along transects or when strong winds and associated high waves may be encountered. Although these recommended restrictions may limit the number of surveys completed during a 5- to 7-day sampling period, they are clearly required to insure that analyses do not violate ANCOVA assumptions.

Measurement Error

Measurement error is a common problem where variables such as the number of animals, percent ice cover, wave height, wind speed and direction, and other factors are estimated from a fast-moving aircraft. Such measurement error can affect the apparent strengths of relationships among dependent and independent (predictor) variables. If two factors have equally strong influences on oldsquaw density, but one factor is measured more precisely than the other, the precisely-measured factor will seem to have a stronger effect. Thus, measurement errors can confound the interpretation and reduce the power of statistical tests.

We have attempted to reduce measurement error to the greatest extent possible in this study by using well-trained and experienced aerial surveyors. Furthermore, as mentioned earlier, we have implemented training sessions designed to enhance the abilities of observers to estimate the number of birds and other variables recorded along aerial survey transects . Regardless of these efforts, some amount of measurement error is inherent in field investigations of this type and is bound to influence analysis design, results and interpretations. Great care and concentration are necessary during aerial surveys to insure that measurement error is reduced to a minimum.

TESTING OF THE MONITORING PROTOCOL, 1990-1991

As mentioned above, the original monitoring protocol was proposed after an extensive review and analysis of historical aerial survey data, and after a series of test aerial surveys in the study areas in early August 1989. The following pages give results of the two years (1990-1991) of subsequent full-scale test surveys, and make recommendations for changes to the protocol based on more field experience and data analyses in 1990-1991.

Desire Considerations

Consideration of Other Independent Variables

The original design for this project suggested that two additional independent variables not previously considered should be recorded and included in future analyses of factors potentially affecting oldsquaw densities in the Industrial and Control study areas. These two additional factors were (1) ***types of industrial activities and levels of disturbance for each transect during each sampling period,*** and (2) ***seasonal upwelling potential and/or seasonal mean wind speed and direction.*** Both of these factors were included in our full-scale field studies in 1990-1991, but, for reasons described below, seasonal upwelling potential was not used in our final analyses.

Disturbance

Types of industrial activities and associated disturbance levels were categorized (Table 3) and recorded during all aerial surveys conducted in 1990 and 1991. Based on activities observed during the surveys, it was usually possible to determine the types, extent and durations of the activities by contacting various industry representatives. In some cases it was obvious that considerable activity and potential disturbance had occurred in the Industrial study area not only during the survey, but also prior to and sometimes after the survey. For the purposes of our data analyses, the type of activity and level of disturbance recorded for the survey period (i.e., observed during surveys, and determined through discussions with industry representatives) was assigned to the relevant aerial survey transect. The types of prease information needed from industry to further consider pre- and/or post-survey-period activities or disturbances was not documented well enough to be useful in our analyses; often such information was not available. In addition, without more details on the long-term responses of oldsquaws to each type of disturbance, including the degree to which they habituate to various activities, it is not clear how long a time frame should be considered in judging disturbance severity.

Seasonal Upwelling Potential

Historical information on seasonal upwelling potential for years prior to the initiation of this study (prior to 1989) was acquired from other researchers at LGL who use this information in analyses of fisheries data (see LGL 1990a,b; LGL et al. 1990a,b). These data were included in two new sets of multivariate analyses, but results indicated no substantial changes in the overall strengths of the relationships between dependent and independent variables. Furthermore, the two factors defining seasonal upwelling potential (wind speed and wind direction) are already inherent in other independent variables, such as the interaction term WSPD x WDIR, and other terms such as NCOMWND and NECOMWND (see above, and Johnson 1990). Also, since seasonal mean upwelling potential is coded as a single annual value, it does not contribute significantly to the proposed monitoring protocol after only two years of sampling. Nevertheless, this annual variable should continue to be recorded, and it should be reconsidered for use in the model at a future date.

Sampling Procedures

The originally proposed sampling procedures involved the expeditious survey of four transects in each of five habitats in each of two study areas during each of three days (replicates) in four 5- to 7-day periods evenly spaced from mid-July to early-September. Thus, surveys were planned on 12 days per year — three survey days in each of four survey periods. However, in both 1990 and 1991, poor weather (heavy ice, high winds, fog and poor visibility, and freezing rain) prevented the completion of several surveys during several sampling periods (Table 4).

In 1990, sampling was done during all four sampling periods, and 11 of the proposed 12 surveys were conducted. However, a full complement of three surveys in each of the two study areas was possible only once, during period 1 (Table 4). Furthermore, it was not possible to conduct useful surveys of any of the offshore transects (Habitat 5, 5 km seaward of the barrier islands) in 1990 because of heavy ice; ice cover was estimated as >60% on all transects in offshore habitats in each of the two study areas. Similarly, nearshore habitats (Habitat 4, 1.5 km seaward of the barrier islands) were surveyed in both the Industrial and Control study areas during only six of the 11 surveys in 1990 (Table 4). Nevertheless, seven surveys of all 12 barrier island-lagoon transects (Habitats 1-3) in both study areas were conducted during the peak of the oldsquaw molt period (18 July through 20 August) in 1990. Data from these seven surveys and three habitats were considered balanced (Milliken and Johnson 1984), and were used in the final ANCOVA.

In 1991 the situation was worse. As in *1990,* heavy ice (estimated >70% cover) prevented useful surveys of offshore transects during every aerial survey, and heavy ice (estimated >60%) also prevented surveys of nearshore transects during all but three surveys (Habitats 4 and 5, Table 4). One complete sampling period was missed because of a long period of freezing rain and fog in early September (Table 4). Nevertheless, eight surveys of all barrier island-lagoon transects (Habitats 1-3) in both study areas were completed during the peak of the oldsquaw molt period (19 July through 21 August) in 1991. Data from these eight surveys and three habitats were considered balanced, and were used in the final ANCOVA.

In retrospect, the test surveys conducted in 1989, a year of fine weather, were insufficient to evaluate the proposed sampling procedures during years when weather and ice conditions are severe. Based on the problems encountered during the two years of intensive field sampling, several recommendations can be made to improve the sampling procedures. These recommendations also affect the experimental design and therefore influence statistical procedures. The recommendations are as follows:

Table 4. The numbers of transects sampled in 5 different habitats on different dates in different sampling periods in the Industrial and Control study areas in the Alaska Beaufort Sea. 1990 and 1991.**

1990

Proposed Sampling Periods	Replicate Surveys in 1990	Industrial Habitats 1	2	3	4	5	Control Habitats 1	2	3	4	5
1	1 18 Jul	4	4	4	4	0	4	4	4	4	0
	2 20 Jul	4	4	4	4	0	4	4	4	4	0
	3 23 Jul	4	4	4	4	0	4	4	4	4	0
2	1 03 Aug	4	4	4	4	0	4	4	4	4	0
	2 04 Aug	4	4	4	4	0	4	4	4	0	0
	3 -	0	0	0	0	0	0	0	0	0	0
3	1 09 Aug	4	4	4	0	0	4	4	4	0	0
	2 16 Aug	4	4	4	0	0	0	0	0	0	0
	3 20 Aug	4	4	4	4	0	4	4	4	4	0
4	1 02 Sep	4	4	4	4	0	4	4	4	4	0
	2 04 Sep	4	4	4	0	0	4	4	4	0	0
	3 05 sep	4	4	4	0	0	4	4	4	0	0

1991

Proposed Sampling Periods	Replicate Surveys in 1991	Industrial Habitats 1	2	3	4	5	Control Habitats 1	2	3	4	5
1	1A 18 Jul	4	4	4	0	0	0	0	0	0	0
	1 19 Jul	4	4	4	0	0	4	4	4	0	0
	2 20 Jul	4	4	4	0	0	4	4	4	0	0
	3 22 Jul	4	4	4	0	0	4	4	4	0	0
2	1 04 Aug	4	4	4	0	0	4	4	4	0	0
	2 10 Aug	4	4	4	0	0	4	4	4	0	0
	3 -	0	0	0	0	0	0	0	0	0	0
3	1 14 Aug	4	4	4	4	0	4	4	4	3	0
	2 16 Aug	4	4	4	4		4	4	4	4	0
	3 21 Aug	4	4	4	4	0	4	4	4	4	0
4	1 -	0	0	0	0	0	0	0	0	0	0
	2 -	0	0	0	0	0	0	0	0	0	0
	3 -	0	0	0	0	0	0	0	0	0	0

** Shaded values were not used in the final ANCOVA (see text).

1. Abandon the concept of several 5- to 7-day sampling periods. Based on our experiences in 1990-1991, weather conditions typically do not allow three surveys to be conducted in all habitats in both study areas on each of three days during each of the four 5- to 7-day sampling periods. A more practical sampling approach involves a series of six to eight replicate surveys conducted during the mid-July to mid- to late August period. This eliminates one level of analysis (i.e., period) in the statistical model, but, as discussed in more detail later, this does not weaken the overall power of the critical ANOVA or ANCOVA tests.

2. Maintain a balanced sampling effort, which is required by ANCOVA (i.e., devote equal sampling effort to each study area during each day of sampling). In other words, ensure that both study areas can be sampled during the same survey day. Both time and air charter costs can be saved if — before commencing a day's survey — both study areas (Industrial and Control) are inspected during a brief reconnaissance flight to ensure that they are fog-free and that wind, waves and ice in each area are within acceptable limits.

3. Do not conduct aerial surveys in either study area, or in particular habitats within either study area, if conditions known to strongly reduce the apparent or actual density of oldsquaws are present, e.g., high winds, high waves, extensive ice cover, etc. In other words, do not conduct surveys in a given habitat in either study area if that habitat in one study area is extensively covered with ice or fog, or under the influence of high winds. This approach maintains the balanced survey design necessary for the ANCOVA, and avoids conducting partial surveys whose results cannot be used in those analyses.

4. Abandon surveys of habitats seaward of the barrier islands. Transects in these habitats are iee-covered too often to allow for systematic aerial survey coverage and, therefore, for them to be included in a balanced ANCOVA. Furthermore, densities of oldsquaws in these habitats are typically low and highly variable, i.e., unsuitable for monitoring.

Schedule of Survevs

The original sampling schedule involved four sets of aerial surveys to be conducted during the mid-July to early September molt period of oldsquaws. Afurther andmore in-depth review of historical oldsquaw molt data (Johnson 1985; LGLunpub. data) indicated that only a small proportion of oldsquaws using barrier island-lagoon habitats are still molting and flightless during early September. By early September, most male oldsquaws have regrown their flight feathers and are able to fly. Furthermore, by early September, females with flying young begin to move into coastal lagoons from mainland lakes and ponds (Johnson and Richardson 1981; Johnson 1985). A more appropriate sampling schedule would cover the period mid-July through mid- to late August. This schedule would ensure that the same segment of the oldsquaw population (molting and flightless males and non-breeders) was sampled during each replicate aerial survey.

Thus, several recommendations can be made to improve the sampling schedule. These recommendations also affect the experimental design and statistical procedures, as discussed in more detail below. The recommended changes to the survey schedule are as follows:

1. Conduct all surveys during the 4- to 5-week period during the peak of the oldsquaw molt (mid-July through mid- to late August). This involves the elimination of the proposed early September aerial survey, and ensures that the same segment of the oldsquaw population is sampled during all surveys.

2. As mentioned earlier, a series of six to eight replicate surveys should be conducted, at about even intervals, throughout the 4- to 5-week sampling period. Considering that poor flying weather is often encountered in the study area during the summer open water period, such a schedule is more practical than attempting to conduct several surveys of all transects in all habitats in both study areas during each of three or four 5- to 7-day blocks of time.

Analysis Procedures

In the above discussion we recommended changes to the original sampling procedures and sampling schedules described in the original monitoring protocol. Here we explain the analysis implications of the recommended changes. We also give the results of our ANOVA and ANCOVA of the data collected in 1990 and 1991. We also evaluate our original null hypotheses, and discuss the power of the statistical procedures used in testing these hypotheses.

The New ANCOVA Model

The final model recommended to monitor densities of molting male oldsquaws in relation to OCS development is as follows:

$$\mathrm{Ln(Density+1)} = \text{constant} + \mathrm{WAVE} + \mathrm{D} + \mathrm{A} + \mathrm{Y} + \mathrm{AY} + \mathrm{H(A)} + \mathrm{YH(A)} + \mathrm{T(H(A))} + \mathrm{YT(H(A))},$$

where wave is a covariate representing the log transformed (Ln(x+1)) wave height (inches) recorded on the transect, ***D*** is a factor representing ***disturbance*** on the transect (Table 3), *A* is factor representing the study ***area*** (Industrial or Control), Y is a factor representing the survey ***year, H*** is a factor representing the ***habitat*** type within which the transect is located, and ***T*** is a factor representing the location of the ***transect*** along a west-east gradient. Parentheses designate that some factors are nested within others, e.g., H(A) indicates that habitat is nested within area. The dependent variable is the natural logarithm of the density of oldsquaws measured each sampling day on each transect, in each habitat, and in each area during a given year.

All factors and covariates used in this model are identical to those used in the earlier multiple regression analyses (Johnson 1990), with the exception that only 1990 and 1991 data have been used in the current model. Also, some covariate names have been changed slightly (e.g., WAVE rather than WAVEHT or WAVETRAN), and some data have been transformed differently than originally recommended, e.g., percent ICE cover has been transformed using an arc sine square route transformation, rather than a log transformation.

This model differs from that recommended earlier (Johnson 1990) because of changes in the sampling procedures and sampling schedules in 1990 and 1991, and because of refinements and re-evaluations of some statistical procedures. The rationale for the structure of the new model is presented below.

Factors

The period factor has been dropped from the model because insufficient replicate surveys could be conducted in some sampling periods, and because it was necessary to drop one whole sampling period (in September) in order to restrict surveys to the peak of the oldsquaw molt period. The elimination of period from the model does not have a significant impact on our ability to test the original null hypotheses. Although the grouping of surveys into periods may help define possible habitat x year interactions, it is done at the expense of a substantial reduction in the degrees of freedom in testing for disturbance effects, which is one of the primary objectives of the study ($H_0$2).

A more detailed consideration of the structure of the proposed model, in particular of disturb ante, suggested that it should be treated as an incomplete blocking (stratification) variable, rather than as a covariate.

The rationale for treating a variable, in this case disturbance (d), as either a blocking variable or a 'covariate' in an ANOVA design, is discussed in Huitema (1980), Milliken and Johnson (1984), and Wirier et al. (1991). Milliken and Johnson (1984) point out that when type III sums of squares are calculated (i.e., when all parameters are estimated using least squares regression techniques), and the variable of interest (disturbance in this case) does not interact with any of the other variables (the usual assumption for a covariate), then the two approaches (blocking variable vs. covariate) differ only in the assumed relationship between the dependent variable (oldsquaw density) and disturbance. This is true even if disturbance does or does not occurs in combination with other factors. When treated as a covariate, the relationship between disturbance and oldsquaw density is assumed linear, and two parameters are estimated. When disturbance is treated as a blocking variable, the deviation from the mean for all d disturbance levels are considered, and d-1 parameters are estimated.

In general, the covariate approach is advantageous because fewer parameters are estimated for more than three levels of disturbance, whereas the blocking approach is advantageous because it is ‘function-free’. If the covariance relationships of oldsquaw density vs. disturbance are not linear (which is not easily discernible with only two seasons of data), then the treatment of disturbance as a blocking variable generally provides greater reduction in the experimental error, and, therefore, results in a more powerful test (Wirier 1971; Wirier et al. 1991). Disturbance is also treated as a blocking factor because it can only be observed at five distinct levels, i.e., it is not a continuous variable.

Only three levels of disturbance have been recorded in this study so far – categories 1, 2, and 3 from Table 3. We assume that disturbance does not interact with any of the treatments, i.e., disturbance always has the same short-term effect on the birds.

Randomization

When the levels of a factor are chosen on a systematic, non-random basis, then the factor is considered a fixed factor, and inference can only be applied to the tested levels. Disturbance, year and area are clearly fixed factors. On the other hand, if the levels are chosen at random from a very large population of potential levels, then the factor is considered random, and any inference extends to the entire population. Although habitats and transects were not selected at random, they were selected from many alternatives (many different flight paths, and many different measurement locations along the flight paths). Hence, these factors are treated as “random” during the analyses. This means that they contribute fewer terms to the expected mean squares for the corresponding statistical tests than would be the case if they were fixed factors for this design (i.e., treating the factors as random would be less powerful in our particular design). However, since habitats and transects were not selected at random, inferences involving these factors should still be restricted only to the tested levels, and should not be extended to the entire population (Milliken and Johnson 1984).

Nesting

If the unique effects associated with one factor are confined to a specific level of another factor, the factors are said to be nested. For example, the measurements taken on a transect can only be considered in the context of both habitat and area. In this case transects are said to be nested within area and habitat. Similarly, the nesting of habitat within area requires that habitat cannot be considered without knowledge of the area. The implicit assumption is that all interactions between area and habitat are confined to each of the study areas. The sums of squares for nested factors can be computed as the sums of the factors used in a fully factorial, or fully crossed, model, i.e.,

$$H(A) = H + HA,$$
$$YH(A) = YH + YHA$$
$$T(H(A)) = T + TA + TH + TAH$$
$$YT(H(A)) = YT + YTA + YTH + YTAH$$

The pooled components YH and YHA are separate measures of the variation of the year x habitat interaction (if habitat is indeed nested within area). The requirement of homogeneity y, which is necessary for pooling in this case, is equivalent to the requirement that the correlations of habitat and year are the same within each of the areas (Wirier 1971). In contrast, if habitat were crossed with area, i.e., if habitat were classified in an identical fashion in each study area (were the same in both areas), then pooling the terms would not be appropriate (Wirier 1971). We tested for homogeneity of YH with YHA to ensure that the requirements for nesting were satisfied. Results showed that mean square error terms for HY and HAY were almost equal (mean square errors of 13.405 vs. 13.6$4, respectively), thus providing some empirical justification for nesting.

A biological justification for nesting habitats within areas is the fact that habitats are not identical in the two study areas. The mainland shoreline of the Control area is characterized by many small bays and lagoons with protective spits and islands (i.e., favored seaduck habitat); such habitats are mostly absent from the Industrial area. Such a difference in habitats between the two study areas would necessitate nesting them within areas.

Expected Mean Square

The expected mean square error terms, and the degrees of freedom used in statistical tests of the factors in this study, are given in Tables 5 and 6. A critical test in this study is for **disturbance** (D), which uses the residual error mean square as the error term (Table 6). This statistical test directly addresses our working hypothesis $H_0 2$. The other important statistical test is the year x **area interaction** (AY). **In** this test we use the interaction of year x habitat within area, YH(A), as the error term (Table 6). This test directly addresses our working hypothesis $H_0 1$.

It is useful to consider the situation where habitat and area are crossed, HA, as discussed in the earlier section, rather than nested H(A), as in the current model (Tables 5 and 6). If this were the case, then the statistical test for the year x area interaction (AY) would use the error term AYH with (y-1)(h-1)(a-1) degrees of freedom, rather than the error term YH(A). The nested design YH(A) has more degrees of freedom [(y-l) (h-1)a] than the pooled design. It should be noted that there is a considerable loss in degrees of freedom (i.e., statistical power) if AYH is inappropriately used as the error term when habitat is truly nested within area, as in the present analysis.

Covariates

Covariates originally considered for the model were **wind speed (WSPD),** transformed wind direction **(WDIR),** northern component of wind **(NCOMWND),** transformed percent ice cover (ICE), and transformed wave height (WAVE). Pearson correlation coeffiaents among all pairs of candidate covariates were computed to identify those that were highly correlated (Table 7). Any statistically non-significant covariates or interactions with year and area were eliminated following the step-wise procedure described in our earlier report (Johnson 1990) and recommended by Bliss (1970) and Huitema (1980).

Repeated Measures and Data Selection

All strata in our final experimental design (unshaded area in Table 4) were measured during each sampling period (survey day). Hence the design was balanced and may be appropriately viewed as a two-factor experiment (year and area were treatments) with a hierarchy of repeated measurements (habitats and transects were measured during each survey in each of the two study areas). Year and area are at a different level of randomization (fixed) compared to habitat and transect (random). For this type of design, tests of the year and year x area interaction are not confounded by differences among habitats and transects (Wirier 1971, Milliken and Johnson 1984). In other words, each survey serves as its own control with respect to year and year x area interaction. The practical implication of this fact for our study design is that, as long as the analysis is restricted to data arising from surveys that are complete (balanced), then the critical test for $H_0 1$ (year x area interaction) is valid regardless of any correlation between or among transects and habitats. This critical test will also remain valid in the presence of additive or carry-over effects (i.e., a situation where an event during one survey may affect the density of oldsquaws in a subsequent survey).

In contrast, the direct measure of disturbance ($H_0 2$) is confounded by differences among habitats and transects. In other words, the univariate test for disturbance is only valid if the measurements taken in a cell (year, area, habitat and transect combination) can be regarded as truly independent replicates.

Table 5. Degrees of freedom and expected mean squares of factor components in the ANOVA of 1990-1991 oldsquaw density data.

Component	Degrees of Freedom	Expected Mean Square
D	d-1	error + ayhtn*Var[D]
A	a-1	error + dyn*Var[T(H(A))] + dytn*Var[H(A)] + dyhtn*Var[A]
Y	y-1	error + dn*Var[YT(H(A))] + dtn*Var[YH(A)] + dahtn*Var[Y]
AY	(a-1) (y-1)	error + dn*Var[YT(H(A))] + dtn*Var[YH(A)] + dhtn*Var[AY]
H(A)	(h-1)a	error + dyn*Var[T(H(A))] + dytn*Var[H(A)]
YH(A)	(y-1) (h-1)a	error + dn*Var[YT(H(A))] + dtn*Var[YH(A)]
T(H(A))	(t-1)ha	error + dyn*Var[T(H(A))]
YT(H(A))	(y-1) (t-1)ha	error + dn*Var[YT(H(A))]

MODEL ln(Density+1) = constant+D+A+Y+AY+H(A) +YH(A)+T(H(A))+YT(H(A))

Factor:	D	A	Y	H	T
Fixed/Random:	F	F	F	R	R
Levels:	d	a	y	h	t

n = number of observations per cell.

Factor Definitions:
D = disturbance
A = area
Y = year
H = habitat
T = transect

Table 6. Test statistics for each of the components in the ANOVA of the 1990-1991 oldsquaw density data (see expected mean squares in Table 5).

Component	Error Term
D	residual error
A	H(A)
Y	YH(A)
AY	YH(A)
H(A)	TH(A)
YH(A)	YT(H(A))
T(H(A))	residual error
YT(H(A))	residual error

Table 7. Pearson correlation coefficients (r) for cross-correlations among potential covariates in the ANCOVA of 1990-1991 oldsquaw density data (n = 360).

	WSPD	COS(WDIR)	NCOMWND	WAVE	ICE
WSPD	1.000				
COS(WDIR)	-0.425**	1.000			
NCOMWND	0.071	0.713”’	1.000		
WAVE	0.644**	-0.075	0.303**	1.000	
ICE	0.100	-0.078	-0.033	-0.001	1.000

** p <<0.01

Computing the Sensitivity (Power) of the ANCOVA Model

An important issue in a monitoring program of this type is the degree to which the sampling and analytical procedures are able to test critical hypotheses. In this study we considered the degree to which the current model can be improved, i.e., made more powerful in order to detect smaller percent changes in the adjusted mean density of oldsquaws for the two terms in the model (disturbance and year x area interaction) that relate to the two hypotheses being tested. We did this by computing the ability of the model to detect given percent changes (at a 95% confidence level) in adjusted mean densities of oldsquaws by (1) increasing the amount of sampling within a year, and / or (2) increasing the number of years of sampling.

Burdick and Graybill (1992:36-39) show how to estimate exact confidence intervals on linear combinations of expected mean squares with different signs, as follows: $\delta = c_1\theta_1 - c_2\theta_2$, where the c's are constants and the θ's are expected mean squares. This form corresponds exactly to our design. For example, the test for the **year x area interaction** sets $\delta = O$, $c_1 = c_2 = 1/(dhtn)$, θ_1 = the expected mean square of the AY component, and 6_2, = the expected mean square of the YH(A) component (see earlier discussion, and Tables 5 and 6). We applied Burdick and Graybill's methodology to obtain the upper 95% confidence level for δ at various sampling regimes (i.e., only y and n can vary). We assumed that the variation about the cell means observed in 1990 and 1991, adjusted for wave height, would remain the same in future years. For convenience in computation, we further assumed that an equal number of surveys would be conducted each year, and that only three levels of disturbance would be recorded. The upper 95% confidence level variance measure was then transformed to the Ln oldsquaw density deviation with the appropriate t-distribution, and expressed as the percentage of the Control area mean observed in 1990 and 1991, and adjusted for wave height (the covariate).

Statistical Software

We found that the best software package available to conduct the ANOVA and ANCOVA procedures for this study is the general linear modeling (GLMH) module in SYSTAT (Wilkinson 1987), This is a powerful and flexible micro-computer based package of programs available for both

DOS and Macintosh operating systems. The balanced design of our sampling program and the requirement for use of Type III sums of squares (SS) (Milliken and Johnson 1984:166-171) for hypothesis testing makes SYSTAT a particularly useful package (Type III SS are the default SS in SYSTAT). The availability of such a user-friendly and well documented package of programs for use in a monitoring protocol of this type is an important aspect of the design and implementation. It reduces the time and expense necessary to set up and execute computer programs for the complex analyses required.

Results of the ANCOVA

As recommended in Johnson (1990), an initial analysis of variance of the 1990-91 data was conducted using no covariates (Table 8, Case A). Three of the terms, h(a), yh(a), and t(ah) were highly significant. The results for h(a) indicated that oldsquaw densities in habitats within areas were different within a year, h(a), as well as between years, yh(a), and that oldsquaw densities in different habitats differed (see also Fig. 7). The results for t(ah) showed that, within areas and habitats, densities on different transects varied in a consistent way. These results are consistent with results from earlier studies (Johnson and Richardson 1981) where densities of oldsquaws were found to be different among habitats and transects in Beaufort Sea lagoons. In fact, as mentioned in the design phase of this project (Johnson 1990), the study areas were originally subdivided into different habitats, with several transects in each habitat, because of suspected differences in oldsquaw abundance in these different locations. One noteworthy result was the difference in oldsquaw densities on transects within habitats and areas, t (ah). Some transects had consistently higher densities of oldsquaws compared to others in the same areas and habitats (see Append. 7). Earlier work on oldsquaws in the study areas has also documented this phenomenon (Johnson and Richardson 1981).

An initial ANCOVA was conducted using all possible covariates. Covariates considered in a preliminary model were ice (arcsine square-root transform of % ice), wspd, wdir (cosine transform), ncomwnd, wave, and all possible interactions with year and area. Since wspd and wdir are the essential components of ncomwnd (ncomwnd = coswdir x wspd), these three covariates (wspd, wdir and ncomwnd) were not used in the same model.

The covariates remaining in the various runs of the model, after sequentially removing non-significant ones (as discussed earlier), are given in Table 8, Cases B and C. Case B shows results for the model that considered wspd, wdir, ice and wave, along with all appropriate interaction terms. In this case the covariates wspd and a x wspd had statistically significant effects on oldsquaw density. Apparent oldsquaw density tended to be lower when wind speed was high (Append. 6F). Case C shows results for the model that considered ncomwnd (rather than wsp d and wdir), ice, wave , and appropriate interaction terms. In Case C, the covariate wave was statistically significant. Apparent oldsquaw density tended to be lower when wave height was high (Append. 6B). The results for the main factors and interactions terms are the same in Cases B and C as those in Case A (described above), with the additional interpretations that observed oldsquaw densities differed significantly according to wind speed (B) or wave height (C).

At first glance, the Case B version of the model appears to be best because of the marginally smaller residual mean square error for d (0.754 vs. 0.763, Table 7, Cases B and C, respectively). However, the model resulting in Case C of Table 7 is recommended for the following reasons:

1. The significant area x wspd interaction in Case B is a confounding factor in the interpretation of the year x area interaction, ay (e.g., there may be a significant ay effect at some level(s) of wind speed, but not at other levels of wind speed).

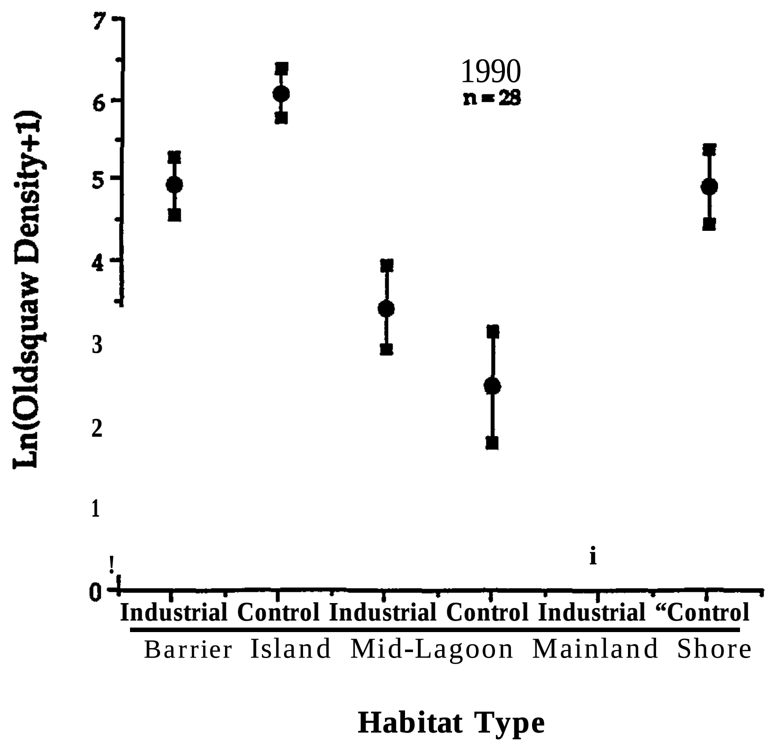
2. Observer efficiency is known to be related directly to wave height, rather than only indirectly (through wave height) to classifications of wind speed.

It is notable that, in all three versions of the model, the three terms h(a), yh(a), and t(ah) were statistically significant. The interpretations and implications of this are discussed above (Case A). Even more significant, however, is the fact that disturbance (d) and the year x area interaction (ay) terms were not statistically significant in any version of the model. So far we have recorded only three levels of disturbance (1, 2, and 3; see Table 3) in the

Table 8. Results of ANOVA and ANCOVA tests of 1990-1991 oldsquaw density data. Three cases are presented: Case A = no covariates; Case B = one covariate, wind speed (wspd); Case C = one covariate, wave height (wave).

Term	SSQ	SSQ(test)	df	df(test)	M S	MS(test)	F	p
Case A: No Covariates, R squared = 0.797								
d	2.824	244.964	2	310	1.412	0.790	1.787	0.169
a	78.087	586.592	1	4	78.087	1%.648	0.532	0.506
y	28.662	53.180	1	4	28.662	13.295	2.156	0.216
ay	28.587	53.180	1	4	28.587	13.295	2.150	0.216
h(a) *	586.592	185.968	4	18	146.648	10.332	14.194	***0.000***
yh(a)	53.180	14.951	4	18	13.295	0.831	16.007	***0.000***
t(ah)	185.968	244.964	18	310	10.332	0.790	13.074	***0.000***
yt(ah)	14.951	244.964	18	310	0.831	0.790	1.051	0.402
Case B **Covariate = WSPD, R squared = 0.807**								
______	*10.553*	232.366	1	308	*10.553*	0.754	13.988	***0.000***
a*wspd	*3.278*	232.366	1	308	*3.278*	0.754	4.345	***0.038***
d	*2.212*	232.366	2	308	*1.106*	0.754	1.466	0.232
a	*36.553*	571.781	1	4	*36.553*	142.945	0.256	0.640
Y	*16.094*	56.291	1	4	*16.094*	14.073	1.144	0.345
ay	*15.338*	56.291	1	4	*15.338*	14.073	1.09	0.355
h(a)	*571.781*	181.09	4	18	*142.945*	10.061	14.208	***0.000***
yh(a)	*56.291*	15.061	4	18	*14.073*	0.837	16.819	***0.000***
t(ah)	*181.09*	232.366	18	308	*10.061*	0.754	13.335	***0.000***
yt(ah)	*15.061*	232.366	18	308	*0.837*	0.754	1.109	0.342
Case C: Covariate = WAVE, R squared = 0.804								
wave	9.151	235.813	1	309	9.151	0.763	**11.991**	-0001
d	2.798	235.813	2	309	1.399	0.763	**1.833**	0.162
a	78.659	538.830	1	4	78.659	134.708	0.584	0.487
Y	34.520	54.179	1	4	34.520	13.545	2.549	0.186
ay	27.544	54.179	1	4	27.544	13.545	2.034	0.227
h(a)	538.830	182.133	4	18	134.708	10.119	13.313	***0.000***
yh(a)	54.179	14.552	4	18	13.545	0.808	16.754	0.000
t(ah)	182.133	235.813	18	309	10.119	0.763	13.259	***0.000***
yt(ah)	14.552	235.813	18	309	0.808	0.763	1.059	0.393

Underlined tern-s in boldface italics are statistically significant ($p \leq 0.05$).



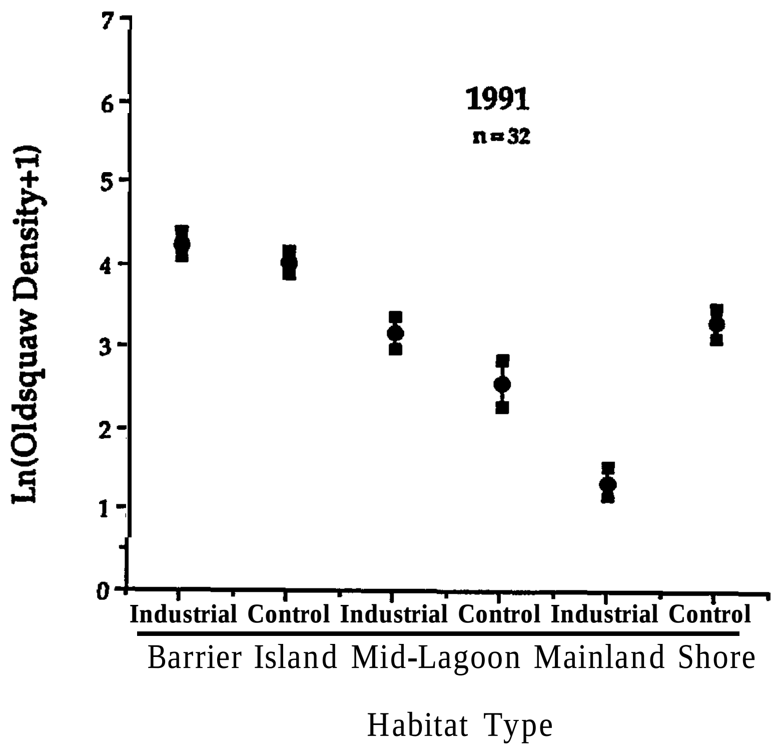


Figure 6. Mean ± 95% C.I. (confidence intervals) of transformed densities [ln(density+1)] of oldsquaws in three barrier island-lagoon habitats (barrier island-lagoon shoreline, mid-lagoon, and mainland shoreline) in both the Industrial and Control study areas in 1990 and 1991.

Industrial study area. Level 3 disturbances were recorded on several transects during survey periods in July and August 1990 (Append. 5) during surveys that overlapped with practice oil spill clean-up exercises that occurred in the Industrial study area (R. Metcalfe, ARCO, pers. comm.). The exercises involved regular boat activity, as well as several low-level (< 500' altitude) fixed-wing and helicopter overflights, on transects near the Kuparuk River delta and West Dock causeway (Fig. 3). Other level 3 disturbances were associated with seismic activity, primarily in the Control study area (Append. 5). Details of disturbances recorded on speafic transects and survey days are given in Appendix 5.

Graphs showing the relationships between transformed oldsquaw density on transects in the two study areas (Industrial and Control) in 1990 and 1991 vs. time of day, transformed wave height, disturbance level, transformed day of season, transect location (W-E), transformed wind direction, and wind speed are given in Appendix 6.

Appendix 7 presents the individual cell means (ln[oldsquaw density + I] adjusted for wave height) by transect, habitat, study area, and year (1990 and 1991). In total, there were 15 complete surveys of the 24 transect/habitat/area combinations in the two years of sampling (7 in 1990 and 8 in 1991, n=360).

Appendix 8 shows the actual mean densities of oldsquaws (adjusted for wave height) in the Control and Industrial study areas in 1990 and 1991. This plot represents the year x area interaction term discussed in detail above.

Evaluation of Hypotheses

The main objective of this study was to devise field and analytical methodology suitable for long-term monitoring of the numbers of molting oldsquaws in relation to potential regional effects ($H_0 1$) and local effects ($H_0 2$) of industrial activity. After an initial season of field tests (1989), two seasons of systematic field data were collected (1990-1991). From a computational viewpoint, the statistical procedures developed in this study can be applied with a minimum of two years of systematic data. However, it is premature to try to evaluate the correctness of the null hypotheses, and particularly $H_0 1$, after only two years of systematic surveys. Thus, interpretations of hypotheses given here are included primarily as an illustration of how such interpretations can be made after more data are collected — not as definitive tests of the hypotheses.

The two null hypotheses to be tested by the monitoring and analysis program are as follows:

> HOI: There will be no detectable change in relative densities of molting male oldsquaws in selected Beaufort Sea index areas.
>
> $H_0$2: Changes in male oldsquaw distribution patterns are not related to OCS oil and gas development activity.

Regional Effects

HOI concerns the possibility of a long-term, i.e., year-to-year, change in oldsquaw densities in the Industrial area that is not paralleled by a corresponding change in the Control area. In our analyses of variance and covariance, the year x area interaction term, a y, provides a test of $H_0$1 after allowance for other factors such as habitat, specific transect, local disturbance, various interaction terms, and (in ANCOVA) covariates such as wind speed or wave height. Based on two years of systematic sampling there is no statistically significant evidence of such a change; the ay term was non-significant in all ANOVA and ANCOVA models (Table 7). However, various industrial activities had been going on in the Industrial areas for many years prior to 1990 as well as in 1990 and 1991. Thus, no significant ay effect would be expected over such a short interval, regardless of whether or not a change in relative use of the Industrial vs. Control areas would occur over the longer term. If systematic surveys are continued in subsequent years when industrial activities in nearshore areas are consistently greater (or less) than in 1990-1991, a corresponding statistical test of the ay term can be used to evaluate whether there is a corresponding long-term change in oldsquaw densities.

The are a term in the ANOVA and ANCOVA results are also instructive. The area term provides a test of the hypothesis that oldsquaw densities were the same in the Industrial and Control regions during the 1990-1991 period as a whole. (This hypothesis should not be confused with the original H_{o1} that “There will be no detectable change in ***relative densities*** of molting male oldsquaws in selected Beaufort Sea index areas."). All ANOVA and ANCOVA models failed to reject this hypothesis of overall equal densities in the two study areas. Inspection of Figure 7 suggests that – in 1990-1991 – there was no consistent difference between the Industrial and Control regions in oldsquaw densities in barrier island habitats or mid-lagoon habitats. This is a noteworthy result, given the history of industrial activity in the Industrial area not only in 1990-1991 but also in prior years. However, densities along the mainland shore were substantially higher in the control area, as mentioned previously, and as reflected in the significant h(a) interaction terms (Table 7). This is believed to be at least partly the result of a difference in the type of habitat along the mainland shoreline in the Industrial vs. the Control areas. It should be kept in mind, however, that there is no *a prior* reason to expect that densities of oldsquaws should be the same in the two study areas. As mentioned above, it is a change in the ***relative densities*** in the two study areas that is the true test of H_{o1}.

Although neither the area term nor the year x area interaction term was statistically significant in the three runs of the model using 1990-1991 data, it is somewhat worrisome that the overall mean density of oldsquaws on barrier island transects in the two study areas (pooled), declined steadily over the 1989-1991 period (Fig. 6, top). At the same time, the general trend in oldsquaw densities on non-barrier island habitats steadily increased (Fig. 6, bottom). The possibility of long-term trends in densities of molting male oldsquaws in nearshore Beaufort Sea habitats can only be evaluated if data from additional years become available. However, results of aerial breeding pair surveys of the Arctic Coastal Plain of Alaska during 1986-1991 (Brackney and King 1991, King 1991) indicate no downward trends in the estimated numbers of oldsquaw drakes, oldsquaw pairs, or in oldsquaw population estimates.

Local Disturbance Effects

$H_0 2$ concerns the possibility that human activities in particular parts of the Industrial (or Control) study areas may have localized influences on oldsquaw densities. In our analyses of variance and covariance, the disturbance term, d, provides a test of $H_0 2$ after allowance for other factors such as area, year, habitat, specific transect, various interaction terms, and (in ANCOVA) covariates such as wind speed or wave height. Based on two years of systematic sampling, there is no statistically significant evidence of such a change; the d term was non-significant in all ANOVA and ANCOVA models (Table 7). However, it is interesting that in the Industrial area in 1990 — the one situation with many cases of potential disturbance — there was a nonsignificant tendency for lower oldsquaw densities on transects with human activities (Appendix 6C).

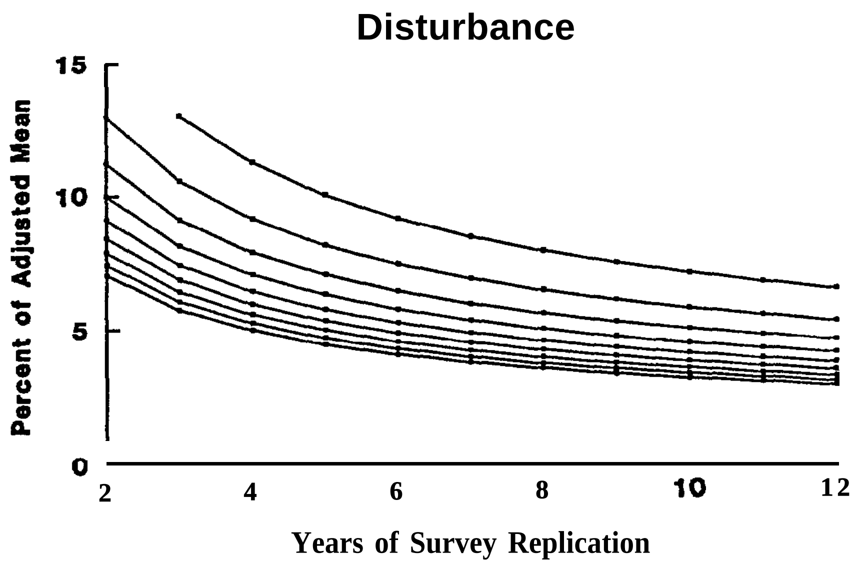
The test of $H_0 2$ is potentially more meaningful than is the test of HOI when only a few years of systematic data are available, given the much larger number of error degrees of freedom for the present test (Table 7). Nonetheless, great caution is necessary in interpreting the results. There were relatively few transect / data combinations with known human disturbance in 1990, and virtually none in 1991 (Appendices 5, 6C). In this situation, the test has little power to detect a biologically significant disturbance effect even if a strong effect exists.

Power of Kev Statistical Tests

As mentioned earlier, an important issue in a monitoring program of this type is the degree to which the sampling and analytical procedures are able to test critical hypotheses. In this study we considered the degree to which the current model can be improved, i.e., made more powerful, in order to detect smaller percentage changes in the adjusted mean density of oldsquaws for the two terms in the model (disturb ante and year x area interaction) that relate to the two hypotheses being tested. We assumed that current conditions would prevail in future years, i.e., only three levels of disturbance at the same relative frequencies would continue to be recorded, and residual error within each cell (year, area, habitat and transect combination) would remain the same.

It is clear that for localized disturbance effects, the current annual level of sampling (seven or eight surveys / season) is adequate to detect, over a 2-year or longer period, a 7-8% change (at a 95% confidence level) in adjusted mean oldsquaw density on disturbed vs. undisturbed transects (Fig. 8). An increase in sampling effort from 7-8 surveys per season, or an increase in the number of seasons of surveys, would not appreciably improve the sensitivity of the model (Fig. 8).

For the year x area interaction term, however, the current level of sampling is sufficient only to detect a 130-140% change in the adjusted mean density of oldsquaws over a 2-year period (Fig. 8). Although the performance of the model is not appreciably improved by increasing the number of samples within a year, it is markedly improved if the number of years of sampling is increased beyond two years. With three years of sampling one could detect a 50% change in adjusted mean density. The current analysis indicates that a 12% difference could be detected only after about 11 or 12 years of surveys. However, if levels of disturbance increase in future years, or if the effects of disturbance are cumulative over several years, then fewer survey years would be required to detect such a change in oldsquaw density.



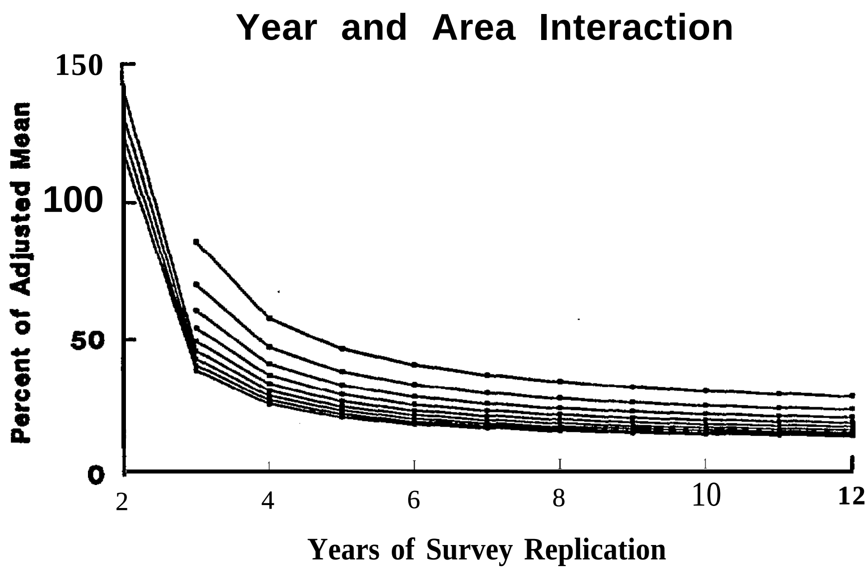


Figure 7. Percent change (95% confidence level) in the adjusted mean density of oldsquaws for tests of disturbance (top) and year x area interaction (bottom), given different amounts Of sampling. Each line 'n 'he top and bottom plots represents a different intensity of within-year sampling, i.e., the bottom lines represent 10 replicate samples per year, and the top lines represents 2 replicate samples per year. The abscissa represents the number of replicate years of sampling, and the ordinate represents the percent change in the mean density of oldsquaws in the Control study area (adjusted for wave height).

SUMMARY AND CONCLUSIONS

In late September 1983, an MMS / NOAA-sponsored workshop was held in Girdwood, Alaska, to develop a monitoring strategy for the Alaska Beaufort Sea. The concept of monitoring Beaufort waterbirds is based on the following conclusions of the 1983 workshop:

> Marine birds are abundant and are a biologically and socially important component of the nearshore Beaufort Sea ecosystem.
>
> Some species of Beaufort Sea marine birds, especially marine waterfowl such as the oldsquaw duck (*Clangula hyemalis),* are ubiquitous, relatively easy to detect and count, and have been well studied prior to industrial development; therefore they are appropriate candidates for monitoring.
>
> A monitoring protocol should be designed to insure that industry-related influences on marine birds are discernible from other natural influences, i.e., should involve a rigorous design and statistical approach that includes both experimental (Industrial) and Control areas and draws on all relevant historical information collected in the study area.

The 1983 workshop identified several potential waterbird species for monitoring. The oldsquaw duck was selected over other species because it is the most abundant and widespread local waterbird in the nearshore Beaufort Sea, the zone where virtually all exploration and development have occurred in the Beaufort marine system. Data presented at the workshop confirmed that during the summer open-water period oldsquaws represent most of the avian biomass in the nearshore Beaufort environment. Most other species occur in smaller numbers or are transients in the study area, so none of these species were thought to be suitable candidates for a monitoring program. During July and August, when oldsquaws molt their feathers, they are flightless and they are thought to be particularly vulnerable to water-borne contaminants and disturbances.

Analyses of nine years of historical aerial survey data in the design phase of this study indicated that oldsquaw ducks represented on average about 93% of all birds of all species seen both on- and off-transect in the central Alaska Beaufort Sea. A very large proportion of oldsquaws recorded during aerial surveys in this area were near barrier islands. These results, along with similar results from studies in the Arctic National Wildlife Refuge (Garner and Reynolds 1986), confirmed the results of the 1983 workshop, i.e., that the oldsquaw was the best candidate for study in a monitoring program designed to detect and measure the effects of industry activities (disturbance) on marine birds and waterfowl in the Jones-Return islands area, Beaufort Sea, Alaska.

A monitoring program that is designed to detect the influences of industry activities on nearby birds must test specific hypotheses that relate to (1) the birds chosen to be monitored, and (2) the types of industry activities in the study area. The following null hypotheses were constructed with such factors in mind:

> HOI: There will be no detectable change in relative densities of molting male oldsquaws in selected Beaufort Sea index areas.
>
> H_o2: Changes in male oldsquaw distribution patterns are not related to OCS oil and gas development activity.

Hypothesis (1) relates to the possibility of a rather large-scale and long-term change in relative densities in Industrial vs. Control study areas. Hypothesis (2) concerns relationships between oldsquaw densities and short-term localized variations in human disturbance.

Correlation analyses of nine years of historical aerial survey data indicated that densities of oldsquaws along barrier island transects best reflected overall densities of oldsquaws in the study area during the sampling periods. Other studies indicated that undisturbed oldsquaws showed a strong diel periodicity in behavior and abundance at barrier island locations *near* the Jones-Return islands, and that oldsquaw distribution near barrier islands was significantly related to wind speed and direction. The results of these and other studies helped in the selection of potential predictor variables for use in preliminary analyses of historical data; multivariate statistical analyses were designed to isolate the most important determinants of oldsquaw density on transects in the study area (Johnson 1990).

The relevant predictor variables (independent variables) selected for use in these preliminary multiple regression analyses of oldsquaw density (dependent variable = DENSTRAN) on transects in the study areas were as follows:

1. *Year* of study (YEAR).
2. Time of the year (day of the season) that sampling occurred (DAY and DAYTRAN).
3. Time of day that sampling occurred (TIME).
4. Water depth in the sampling area (DEPTH and DEPTRAN).
5. Location of transect along an east-west axis (WESTEAST and WESTRAN).
6. Proximity of transect to a barrier island (DIST, DISTRAN, and HABITAT).
7. Wind speed and direction in the sampling area during the sampling period (WDIR, WSPD, ORDWND, NECOMWND, NCOMWND).
8. Percent ice-cover on-transect in the study area during the sampling period (ICE and ICETRAN).
9. Wave height on-transect during the sampling period (WAVEHT and WAVETRAN).
10. Study Area (AREA), i.e., Industrial vs. Control.

Earlier analyses, and analysis of residuals from this multiple regression analysis, indicated that some variables should be transformed to satisfy various assumptions of the parametric general linear modeling (glm) statistical procedures used in this study.

Two multiple regression analyses of oldsquaw densities were conducted: (1) for oldsquaws on transects surveyed during the open-water season (5 June to 23 September), and (2) for those on transects surveyed during the peak period of molt by male oldsquaws (I5 July to 25 August). Results from 9 years of study (1977-1984 and 1989) indicated that several variables and combinations of variables (interaction terms) were highly significant in predicting oldsquaw density on transects in the study area. In particular DAY, WAVETRAN, HABITAT, YEAR x AREA, TIME x HABITAT,

HABITAT x ICETRAN and WDIR x WSPD were statistically significant predictors of oldsquaw density (Table 2) in one or the other of the two analyses. HABITAT was a particularly important predictor variable, especially in combination with TIME and ICETRAN, and this factor was selected to represent the array of other factors describing the proximity of the transect to the barrier islands in the study area.

The results of the multiple regression analyses helped in the design and implementation of the full season sampling programs in 1990 and 1991, and in the formulation of a specific analysis of covariance (ANCOVA) model suitable to analyze 1990, 1991, and any subsequent comparable data collected in the Industrial and Control study areas.

Sampling was conducted in such a way as to obtain oldsquaw density data and associated environmental data for the following spatial and temporal categories:

- Two study areas (Industrial and Control).
- Three habitat strata: (1) barrier island habitat, (2) mid-lagoon habitat, (3) mainland shoreline habitat.
- Four transects within each habitat stratum per area.
- One 4- to 5-week sampling period during the peak of the oldsquaw molt period (mid-July to late August).
- Six to eight relatively evenly spaced survey dates within the single 4- to 5-week sampling period.

For every transect surveyed, we determined the number and density of oldsquaw present, presence of human disturbance, wave height, ice cover and wind.

This sampling approach provides the replicated and structured data necessary to isolate the effects of the variables known to affect oldsquaw densities. The experimental design is compatible with the powerful ANOVA and ANCOVA statistical procedures that we have used to separate the effects of factors and covariates.

In order to test the two null hypotheses presented at the start of this exercise, i.e., to test whether there have been regional or local changes in densities of molting male oldsquaws that may be attributable to industrial activities, we recommend continued use of the analysis of covariance statistical approach. The 5 factors are year, area, habitat, transect, and disturbance level, and the five covariates considered were WSPD, WDIR, NCOMWND, WAVETRAN, and ICETRAN on each transect; WAVETRAN was the single covariate remaining after completion of further analyses. The replicates are the six to eight days of surveys within the single 4- to 5-week sampling period.

The ANCOVA model most appropriate and best suited to test for significant differences in oldsquaw densities over space and time is as follows:

Density= Mean+ WAVE+ D+A+Y+AY+H(A) +YH(A) +T(AH) +YT(AHA) +error

Parentheses indicate that some factors are nested within others, e.g., H(A) is interpreted as habitat nested within area. The ANCOVA model is nested (habitat within study area, transect within habitat) and factor effects are mixed, i.e., some are fixed and some are random. Year, area, and disturbance are fixed effects, but habitat and transect are considered random effects since they could have been defined in a number of different ways. WAVE is the single covariate included in this final model.

Because of the nested design and mixed (random and fixed) effects, tests of significance of the various terms and interactions in the analysis model involve error terms that are specific to the particular test, i.e., terms other than residual error are sometimes used as the denominator of the F-ratio. We have followed the appropriate analysis of covariance (ANCOVA) procedures, as suggested by Bliss (1970), Huitema (1980), and others. The ANCOVA identifies how much of the variation in densities of oldsquaws is attributable to each factor, i.e., year, study area, disturbance, habitat, transect, and to the single covariate, wave height.

The main objective of this study was to devise field and analytical methodology suitable for long-term monitoring of the numbers of molting oldsquaws in relation to potential regional effects (H_01) and local effects (H_02) of industrial activity. After an initial season of field tests (1989), two seasons of systematic field data were collected (1990-1991). However, it is premature to try to evaluate the correctness of the null hypotheses, and particularly H_01, after only two years of systematic surveys. Thus, interpretations of hypotheses given here are included primarily as an illustration of how such interpretations can be made after more data are collected — not as definitive tests of the hypotheses.

HOI concerns the possibility of a long-term, i.e., year-to-year, change in oldsquaw densities in the Industrial area that is not paralleled by a corresponding change in the Control area. In our analyses of variance and covariance, the year x area interaction term, ay, provides a test of H_01 after allowance for other factors such as habitat, specific transect, local disturbance, various interaction terms, and (in ANCOVA) covariates such as wind speed or wave height. Based on two years of systematic sampling there is no statistically significant evidence of such a change; the ay term was non-significant in all ANOVA and ANCOVA models. However, various industrial activities had been going on in the Industrial areas for many years prior to 1990 as well as in 1990 and 1991. Thus, no significant ay effect would be expected over such a short interval, regardless of whether or not a change in relative use of the Industrial vs. Control areas would occur over the longer term. If systematic surveys are continued in subsequent years when industrial activities in nearshore areas are consistently greater (or less) than in 1990-1991, a corresponding statistical test of the ay term can be used to evaluate whether there is a corresponding long-term change in oldsquaw densities.

The area term in the ANOVA and ANCOVA results is also instructive. The area term provides a test of the hypothesis that oldsquaw densities were the same in the Industrial and Control regions during the 1990-1991 period as a whole. (This should not be confused with the original H_{01} that "There will be no detectable change in ***relative densities*** of molting male oldsquaws in selected Beaufort Sea index areas."). All ANOVA and ANCOVA models failed to reject this hypothesis of overall equal densities in the two study areas. Inspection of Figure 7 suggests that – in 1990-1991 – there was no consistent difference between the Industrial and Control regions in oldsquaw densities in barrier island habitats or mid-lagoon habitats. This is a noteworthy result, given the history of industrial activity in the Industrial area not only in 1990-1991 but also in prior years. However, densities along the mainland shore were substantially higher in the control area, as mentioned previously, and as reflected in the significant h(a) interaction terms (Table 7). his is believed to be at least partly the result of a difference in the type of habitat along the mainland shoreline in the Industrial vs. the Control areas. It should be kept in mind, however, that there is no *a* prior reason to expect that oldsquaw densities would be the same in the two study areas. It is a change in the ***relative densities*** in the two study areas that is the true test of $H_{o}1$.

Although neither the area term nor the year x area interaction term was statistically significant in the three runs of the model in 1990-1991 data, it is somewhat worrisome that the overall mean density of oldsquaws in the two study areas (pooled), especially on barrier island transects, declined steadily over the 1989-1991 period. It is also noteworthy that the proportions of oldsquaws, relative to other species of marine birds recorded during surveys, appears to have declined in recent years (Append. 9). The possibility of a long-term downward trend in oldsquaw numbers can only be evaluated if data from additional years and over a wider area become available.

H_02 concerns the possibility that human activities in particular parts of the Industrial (or Control) study areas may have localized influences on oldsquaw densities. In our analyses of variance and covariance, the disturbance term, d, provides a test of H_02 after allowance for other factors such as area, year, habitat, specific transect, various interaction terms, and (in ANCOVA) covariates such as wind speed or wave height. Based on two years of systematic sampling, there is no statistically significant evidence of such a change; the d term was non-significant in all ANOVA and ANCOVA models. However, it is interesting that in the Industrial area in 1990 — the one situation with many cases of potential disturbance — there was a nonsignificant tendency for lower oldsquaw densities on transects with human activities.

The test of H_02 is potentially more meaningful than is the test of H_o1 when only a few years of systematic data are available, given the much larger number of error degrees of freedom for the present test. Nonetheless, great caution is necessary in interpreting the results. There were relatively few transect/data combinations with known human disturbance in 1990, and virtually none in 1991. In this situation, the test has little power to detect a biologically significant disturbance effect even if a strong effect exists.

As mentioned earlier, an important issue in a monitoring program of this type is the degree to which the sampling and analytical procedures are able to test critical hypotheses. In this study we considered the degree to which the current model can be improved, i.e., made more powerful, in order to detect smaller percentage changes in the adjusted mean density of oldsquaws for the two terms in the model (disturbance and year x area interaction) that relate to the two hypotheses being tested. We assumed that current conditions would prevail in future years, i.e., only three levels of disturbance at the same relative frequencies would continue to be recorded, and residual error within each cell (year, area, habitat and transect combination) would remain the same.

It is clear that for localized disturbance effects, the current annual level of sampling (seven or eight surveys/season) is adequate to detect, over a 2-year or longer period, a 7-8% change (at a 95% confidence level) in adjusted mean oldsquaw density on disturbed vs. undisturbed transects.

For the year x area interaction term, however, the current level of sampling is sufficient only to detect a 130-14070 change in the adjusted mean density of oldsquaws over a 2-year period. Although the performance of the model is not appreciably improved by increasing the number of samples within a year, it is markedly improved if the number of years of sampling is increased beyond two years. With three years of sampling one could detect a 50% change in adjusted mean density. The current analysis indicates that a 12% difference could be detected only after about 11 or 12 years of surveys.

We are confident that the monitoring plan presented above is the most appropriate and statistically defensible approach given the present state of information. However, as mentioned in our previous report (Johnson 1990), it is inevitable that, after several years of data collection and subsequent analyses, it will be necessary to further modify some aspects of the field procedures or some of the analyses to further improve the study.

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APPENDICES

Appendix 1. Individual on-transect densities of oldsquaws on transects in the Jones-Return and Stockton-Maguire-Flaxman islands, Alaska Beaufort Sea, 5 June to 23 September 1977-1984 and 1989-1991.

Appendix 1. Individual on-transect densities of oldsquaws on transects in the Jones-Return and Stockton-Maguire-Flaxman islands, Alaska Beaufort Sea, 5 June to 23 Sep tember 1977-1984 and 1989-1991.ª

Survey Date	Overall Study Area			Barrier Island Transect Nos. and Areas Sampled (e-q. km)								Non-barrier Island Transect Nos. and Areas Sampled (w. km.)								
1%%1991	Total Sq. Ian. On-transect	Total # Oldsq. On-transect	Overall Dens. Oldsq./sq. km	23 452	31 5.68	201 8.48	202 608	133 6.0.9	13A 4.84	133 5.40	136 6.28	10 9.48	11 6.04	12 5s6	13 3.48	22 3.64	24 4.40	23 4.80	30 5.00	32 5.72
5 Jun.77	54.08	3	0.06			0.00	0.00													
20 Jun.77	54.08	34	0.63			7.53	230													
5 Jul.77	54.08	745	13.78			saw	61.18													
28-29 Jul.77	54.08	35350	653.66			1090.80	345.07													
15 Aug.77	28.32	13002	635.63			1894.34	1496.71													
30 Aug.77	34.08	4237	79.27			443.40	48.68													
22 Sep.77	34.08	14937	276.20			75.71	0.56													
23 Jun.78	74.4	107	1.44	15.93	1.76	224	aoo										0.00			1.05
5 Jul.78	11208	3305	29.49	8.85	6.87	92.22	264.14	1.31	10.54	2.22	0.80						0.00			11.71
15 Jul.78	74.4	3W72	440.47	86.95	1159.74	1655.90	1148.63										0.45			6.47
25 Jul.78	111.44	%95	87.00	0.00	465.49	330.07	236.84	23.19	0.00	48.15	165.45						0.00			3.50
3-6 Aug.78	117.72	12141	103.13	36.5o	457.04	375.59	272.35	10.53	3.86	464.81	389.17						0.00			8.04
15 Aug.78	74.4	18307	246.06	91.81	352.82	1785.97	60.53										45.43			14.86
25 Aug.78	111.44	19369	173.81	60619	346.13	578.89	18.92	12.99	294.63	10ZS.U3							273			3437
5-6 Sep.78	117.72	19951	169.48	25A5	251.94	39.03	313.32	113.98	17.77	244.26	702..%						76.32			33.64
15 Sep.78	68-68	43s3	6s%	34.07	0.35	11.06	99.01										74.32			
23 Sep.78	117.72	21762	184.86	337.52	13.03	11.79	7.73	12599	1377.69	364.26	129.62						84.55			29.10
22 Jun.79	74.4	33a	5.22	18.81	44.37	3.S4	0.99										0.23			z62
23 Jul.79	117.72	24539	203.45	0.44	700.18	404.s3	702.30	35a%	2273	382.22	607.32						3.64			4.s5
31 Aug.-1 Sep.79	64.28	5560	86.50	5.97	23705	76.77	84.87													
22 Sep.79	74.4	3670	76.21	18.36	58.27	280.28	170.23										5.12			21.50
2 Aug.80	117.72	27826	226.s7	63.50	1205.63	81262	438.65	291.45	20.66	162.02	586.62						0.00			71.68
18 Jul.81	63.36	1775	27.36	15.49		10s88										1.65	8523	0.15		
29 Jul.81	71.44	10751	150.49	98A5		247.44	89293									0.00	0.00	a62		
2 Aug.81	9512	13267	160.50	71.02	154.03	335.61	225.00	10609	26243	238.15	294.11						74.55			12za3
12 Aug.81	59.%	1090	18.18	67.92		123a	92.43									0.02	1.36	am		
29 Aug.81	71.44	1432	20.04	2.03		91.51	52.30									34.07	13.86	mm		
11 Sep.81	71.44	19976	279.62	1596,24		123.00	117.27									137.22	1469.09	510.42		
18 Jul.82	95.36	3817	4a03	44.03	124.47	144.34	10Z3U									6.32	23.43	0.21	240	73.43
31 Jul.82	71.44	9214	128.93	126.99		212.97	38s.s3									104.40	42.73	2.92		
14 Aug.82	77.12	19416	232.76	161.50	1602.46	838.44	1053.62									98.08	10.23	2.08		
28 Aug.82	9X46	5650	59.23	141.81	281.51	142.69	73.6s									4.40	42.05	7292	Soo	7.69
23 Sep.82	95.36	8867	9298	3827	1s.s3	157.31	29.63									0.00	4.09	50.21	a20	47.90
29 Jul.83	7273	6305	86.69	84.%													10.45			
8 Aug.84	13s88	2839?	212.12	693.81	263.73	285.73	736.33	347.20	308.26	254.81	87293					100.00	63.64	0.00	I zoo	70.28
6 Aug.89	176.%	31334	176.90	84.73	1366.90	92.02	13.65	739.62	321.49	703.70	1131.21	0.00	2.48	0.00	0.02	0.00	0.00		0.00	10.49
8 Aug.89	176.96	35060	193.12	230.53	2060.21	817.02	505.43	592.43	23.76	269.07	' 005.25	0.21	0.00	0.00	0.00	0.03	0.00		0.00	0.00
9 Aug.89	176.96	44611	252.10	467.92	2025.00	628.17	370.23	731.25	450.83	435.19	2000.80	0.00	1.82	0.00	0.00	%.15	7.95		1.41	0.04
18 Jul.90	186.36	19400	104.10	97.79	156.87	124.77	55.61	2s4.ss	22235	244.63	3%.83					15.3s	3.41	1.23	1.81	24.63
20 Jul.90	186.36	19097	102.47	50.88	151.94	110.33	210.20	35393	155.79	486.67	4s4.S5					12.36	1.14	1.04	9.68	15.36
73 Jul.90	186.36	16340	142.41	99.78	394.19	590.38	397.s3	261.92	239.30	446.11	549.68					6.87	1.14	am	0.00	15.03
3 Aug.90	186.36	423%	228.57	3%35	264.08	612.91	872.20	532.07	353.61	1146.48	141608					0.00	.318	1.23	0.00	123.95
4 Aug.90	16628	2%14	173.97	17.04	6Z68	188.15	247.20	256.09	5289	139.44	1218.31					0.00	2.73	0.00	aoo	156.99
9 Aug.90	143.20	16953	118.S9	36.73	91.37	111.74	81.41	888.98	S33.47	431.85	348.73						22.73	0.00		54s3
16 Aug.90	722S	6657	9210	26.11	249.30	671.60	18.03										4.09	0.00		0.17
20 Aug.90	186.36	34820	186.34	97.57	230.28	211.74	40.79	953.62	1347.11	12S5.19	933.92					04-2	31.39	6.25	3.23	14.16
2 Sep.90	18636	3655	46.60	4A2	3.52	9.15	35.69	431.48	437.81	129.44	262.26					0.00	0.00	0.00	0.00	0.52
4 Sep.90	143.20	67z9	46.98	0.44	34.15	29.46	17.76	199.51	67.56	16s.56	1%.18						a23	2.71		7.52
5 Sep.90	143.20	18648	130.36	5.09	19.19	2758	11.18	727.32	244.11	116.67	1466.40						4.32	3.75		0.00
18 Jul.91	72.42	3739	51.20	17.70	104.05	170.75	233.93										Z05	0.00		1.22
19 Jul.91	115.60	7253	61.88	75.00	74s26	174.29	162.99	78.13	20.43	9204	1 95.22						9.55	aoo		15.03
20 Jul.91	115.60	6963	6a23	60.23	1 05.62	31.26	212.25	29.77	15.92	21.67	1 ml.12						9.5s	0.21		25.00
22 Jul.91	115.60	9673	83.68	67.04	112.68	252.36	83.72	80.43	3678	149.81	185.19						3.41	0.00		33.22
4 Aug.91	115.60	SS70	75.00	90.27	91.73	98.23	136.68	97.37	113.64	115.00	63.54						7.03	2.08		41.%
10 Aug.91	113.60	6628	57.34	23.44	28.3S	109.91	88.82	131..58	3616	73.33	33.02						1.36	1.46		144.58
14 Aug.91	139.00	63s3	49.52	21.90	144.19	166.98	162.s3	87.17	4669	35.19	30.00						9.32	3.13		55.94
16 Aug.91	138.76	626s	40.72	6.19	36.33	86.79	25.00	190.30	12.81	4%33	35.51					2.75	Z27	3.75	0.60	36.89
21 Aug.91	158.76	5248	33.06	12.S3	57.64	3S.61	63.82	154.61	3079	2556	7.32					5.22	63-3	a42	17.20	17.48
n .	58	S8	58	32	44	57	56	31	31	31	30	3	3	3	3	23	30	31	16	41
Mean =	103.32	13%6.79	133.83	12a40	35932	317.01	247.02	296.11	235.72	314.46	334.09	0.07	1.43	0.00	0.00	27.20	43.39	21.51	3.53	33.76
s.d. =	44.62	11515.11	131.55	254.56	528.90	429.82	324.71	275.39	364.32	327.97	515.93	0.12	1.28	0.02	0.00	44.3s	205.93	9Z04	5.29	40.63
c.v. =	0.41	0.83	a98	2.11	1.47	136	1.31	0.93	1s3	1.04	a97	1.73	0.90	0.00	0.00	1.63	4s6	4.28	1.52	1.20

ª See Figures 3 and 4 for transect locations.

Appendix 1. Continued.'

Survey Date	Non-bank Island Transect Nos. and Areas Sampled (sq. km.)																					
1 % ' 7 -	1 9 9	1 3 3	3 0 5	1 5 2	3 3	6 0	6 1 6	2 6	3 1	0 1	102	301	3 0 2	4 0 2	4 0 2	180	181	182	183	190	191	192	193
	7.52	**4.72**	4.24	**4.28**	3.64	.576	4.44	4.32	5.36	8.44	6.00	6.92	5.24	7.28	5.64	**5.68**	4.24	**5.16**	5.64	6.26	4.48	7	9.84
5 Jun.77										0.00	0.00	0.00	0.00	0.00	2.13								
20 Jun.77										0.00	0.00	0.00	0.00	0.82	2.84								
5 Jul.77										0.12	5.011	4.92	o.3a	119.23	44.68								
23-29 Jul.77										0.12	6.67	7223	1505.73	1550.55	2741.41								
15 Aug.77														1124.73	35.46								
30 Aug.77										5.43	0.17	143.3s	244.08	42857	71.63								
22 Sep.77										5.21	0.83	6X45	1458.78	27653	1334,04								
23 Jun.78										0.00	0.00	0.00	0.00	0.41	0.00								
5 Jul.78										0.24	0.00	3.s0	7.44	3.43	a33	24.47	107.78	0.00	0.00				
15 Jul.78										Z%	1.67	14.74	72.14	29.69	111.03								
25 Jul.78										18.26	2.17	82.80	62.02	28.43	7.09	4.40	11.79	0.00	0.00				
.5.6 Aug.78										0.36	0.33	53.76	75.76	11.40	0.00	183.10	117.62	0.00	0.00				
15 Aug.78										0.00	0.00	4.77	10.88	am	0.00								
25 Aug.78										52.37	43.33	24.86	43.42	0.00	1.77	1.07	0.00	0.00	0.00				
5-6 Sep.78										2370	14.50	11.13	14.12	0.14	0.00	309.15	1354.01	206.39	18.97				
153ep.7Ll										16315229.30		X4.24	25.57	2.06	13.63								
23 Sep.78										2.61	0.00	369.36	56.30	157.69	114.54	438.03	79.01	aoo	152.30				
22 Jun.79										0.00	0.00	0.00	0.00	am	0.53								
28 Jul.79										0.00	9.43	131.21	136.45	41.48	17.73	18.84	104.01	23.26	0.00				
31 Aug.-1 Sep.79										6.37	43.33	98.70	640.29	am	0.00								
22 Sep.79										19.79	9.34	5.76	0.57	76.10	162.59								
2 Aug.80										0.00	0.00	250.87	61.33	134.71	213.43	0.00	16.98	0.00	0.00				
18 Jul.81										107.94	0.00	53.23	2639	9.75	&76								
29 Jul.81										0.00	0.17	129.48	177.67	0.00	0.35								
2 Aug.81										0.00	0.00	51.16	233.59	37.23	27.66	3222	20.05	0.00	0.00				
12 Aug.81										0.00	0.00	7.37	6.87	0.27	4.79								
29 Aug.81										8.03	033	15.32	8.02	am	am								
116ep.81										71.36	18.00	194..97	20.42	0.69	1.24								
18 Jul.82	2.66									0.12	0.00	12.86	5S.34	5.91	9.04								
31 Jul.82										0.12	0.00	386.99	193.31	22.80	11.70								
14 Aug.82										1.18	0.00	28.12	0.38	am	am								
28 Aug.82	19.95									1031	1.50	58.09	94.08	0.00	0.00								
23 Sep.82	419.68									8.S4	0.00	234.77	197.90	17.17	73.58								
29 Jul.83																							
8 Aug.84	0.00									7.94	0.00	209.54	387.60	0.00	0.00	101.76	227.19	113.37	7.80				
6 Aug.89		3.18	aoo	0.00	0.00	0.00	0.00	am	0.00	0.00	0.00	276.01	318.70			0.00	0.00	322.29	0.00				
8 Aug.89		0.00	0.00	0.00	0.00	aoo	0.00	0.00	0.00	0.00	0.00	79.48	0.37			4.40	2358	25.43	0.00				
9 Aug.89		0.00	7.08	5.79	0.00	am	0.00	am	0.00	0.00	033	14.45	0.57			0.00	0.00	211.24	39.01				
18 Jul.90	0.00					36.89	41.32	0.00	0.00	8.29	0.00	227.75	26.72	7.28	am	62.68	195.52	34.88	0.00	49a03	3n32	165.29	6362
20 Jul.90	1.20					0.35	1.56	0.22	a36	18.84	0.00	147.40	33.21	7.01	0.00	144.72	66.75	34.30	21.28	200.32	24263	160.14	77.%
23 Jul.90	aoo					0.00	223	0.00	0.00	039	0.00	39.39	17.75	2.47	a33	22.1 8	2 3 6	0.19	2.46	387.64	45246	216.37	53.25
3 Aug.90	1.06					am	0.00	aoo	0.00	13.63	230	130.64	26.72	am	4.'26	67.61	34.25	4.84	0.00	1.97.03	802.23	153.00	100.00
4 Aug.90	0.00									0.00	0.00	112.86	34.35	a%	0.00	1320	29.25	26.74	2.66	3193	277.01	150.37	32.01
9 Aug.90	1.20											39.97	.%30	0.14	0.18	31.16	41.04	14.15	0.00	36.23	189.06	56.00	25.91
16 Aug.90	a27											7.23	439	261	am								
20 Aug.90	2.93					0.00	0.00	2.21	0.00	4.27	0.00	19.32	222.14	4.%	1.06	0.35	aoo	27.32	0.00	43.09	406.s72	234.43	2,13
2 Sep.90	14.10					aoo	0.22	am	0.00	0.00	0.00	15.46	1.34	69.00	0.18	44.34	13.21	a97	1.95	18.20	40.83	35.00	4.27
4 Sep.90	598											19.94	6.11	am	0.33	37.32	8.02	237.21	3.72	24.21	72.65	31.00	5.1s
5 Sep.40	14.63											1.54	3.24	1.10	a33	0.00	0.47	62.02	192,73	3.01	140.40	48.86	20.33
18 Jul.91	0.13											12.43	5.73	5.22	Z34								
19 Jul.91	4.63											22.40	12.60	7.42	0.18	23.06	7.53	6.78	0.00	43.7o	108.04	23.29	4 3 7
20 Jul.91	14.36											30.35	15.46	11.40	4.%	5.11	7.78	4.84	0.35	11.78	70.76	33.00	8,84
22 Jul.91	0.66											27.89	10.69	19.29	0.18	66.90	63.44	116.67	0.00	67.20	101.34	30.71	50.81
4 Aug.91	13.%											76.39	86.26	16.48	13.48	3644	34.67	61.24	0.3S	49.32	78.13	83.14	44.31
10 Aug.91	10.24											69.94	10.31	13.32	1.77	30.11	16.04	67.44	0.53	39.65	94.64	38.43	17.28
14 Aug.91	aoo						430	am		0.39	0.00	41.47	16.41	2.34	14.18	0.00	2830	75,39	0.00	101.43	10.71	6571	5,89
16 Aug.91	1.33					23.44	65.99	23.23	1.31	0.47	1.67	138.87	14752	1.92	0.00	35.21	2333	33.72	0.18	19.90	9.60	9.71	8,94
21 Aug.91	1.73					9.20	430	11.06	30.22	0.47	10.33	217.77	9.16	3.57	0.18	10.21	30.66	46.32	0.02	10.19	33.26	Z36	2.44
n =	2 4	3 3	3 3	1 1	1 2			1 2	1 1	4 6	4 6	3 4	5 6	54	54	31	31	31	31	1 8	1 8	1 8	1 s
Mean =	2211	1.03	2.36	1.93	0.00	6.35	10.04	3.06	Z92	1226	8.s3	91.24	123.85	78.82	93.63	36,39	86.60	38.24	1434	114.25	194.56	83.43	29.3.5
s.d. =	34.90	1.84	4.09	334	0,00	12.45	21.14	7.10	9.06	30.39	?4.69	119.34	288,24	263.10	410.59	9623	241.71	81.83	4334	143.19	204.70	7382	29.41
c.v. .	3.84	1.73	1.73	1.73	0.00	1.96	2.10	2.32	3.11	2.48	3.93	1.30	233	3.34	4.38	1.71	279	1.41	3.02	1.27	1.05	0.86	1.00

• See Figures 3 and 4 for trane-set locations.

Appendix 2. SYSTAT multiple regression analysis output for the complete season (5 September to 23 September 1977-1984. and 1989) in the central Alaska Beaufort Sea.

```
USE 'HD84:Applications:Statistics:Systat Modules:863txt'
'ARIABLES IN SYSTAT FILE RRE:

      DENS      DENSTRAN       YERR        DAY       TIME
     DEPTH      DEPTRAN    WESTEAST    WESTRAN       DIST
   D 1 STRAN       WSPD        WDIR     ORDWND   ORDWTRAN
   NCOMWND     NECOMWND         ICE    ICETRAN     WAVEHT
   DAYTRAN     WSPDTRAN    WAVETRAN   HRB 1 TRT      RRER
CATEGORY HABITAT=5
CATEGORY RRER=2
MODEL DENSTRAN=CONSTANT+YEAR+DAY+DAYTRAN+TIME+WESTEAST+WSPD+WDIR+WSPD*WDIR+,
ICETRAN+WAVETRAN+HABITAT+AREA+YEAR*AREA+HABITAT*DAYTRAN+HABITAT*TIME+,
HABITAT*WSPD+HABITAT*WDIR+HABITAT*WAVETRAN+HABITAT*ICETRAN
PRINT LONG
ESTIMATE
```

SYSTAT VERSION 3.2 COPYRIGHT, 1988 SYSTAT, INC.
YOU ARE IN MGLH MODULE

DEP VAR:DENSTRAN N: 474 MULTIPLE R: .758 SQUARED MULTIPLE R: .574

ESTIMATES OF EFFECTS $B = (X'X)^{-1}X'Y)$

		DENSTRAN
CONSTANT		-2.179
YEAR		-0.038
DAY		0.097
DAYTRAN		-0.001
TIME		0.001
WESTEAST		-0.054
WSPD		0.003
WDIR		-0.003
WSPD WDIR		0.000
ICETRAN		-0.047
WAVETRAN		-0.376
HABITAT	1	-0.229
HABITAT	2	3.911
HABITAT	3	-4.105
HABITAT	4	1.513
AREA	1	-0.010
YEAR AREA	1	0.016
HABITAT DAYTRAN	1	-0.000
HABITAT DAYTRAN	2	0.000
HABITAT DAYTRAN	3	0.000
HABITAT DAYTRAN	4	0.000
HABITAT TIME	1	0.002
HABITAT TIME	2	-0.003
HABITAT TIME	3	0.002

HABITAT TIME	4	-0.002
HABITAT WSPD	1	0.004
HABITAT WSPD	2	-0.006
HABITAT WSPD	3	0.062
HABITAT WSPD	4	-0.044
HABITAT WDIR	1	0.001
HABITAT WDIR	2	0.000
HABITAT WDIR	3	-0.002
HABITAT WDIR	4	0.004
HABITAT WAVETRAN	1	0.227
HABITAT WAVETRAN	2	0.329
HABITAT WAVETRAN	3	-0.754
HABITAT WAVETRAN	4	0.080
HABITAT ICETRAN	1	-0.357
HABITAT ICETRAN	2	0.001
HABITAT ICETRAN	3	-0.051
HABITAT ICETRAN	4	0.119

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
YEAR	3.632	1	3.632	1.296	0.256
DAY	55.006	1	55.006	19.622	0.000
DAYTRAN	0.412	1	0.412	0.147	0.702
TIME	2.849	1	2.849	1.016	0.314
WESTEAST	1.442	1	1.442	0.515	0.474
WSPD	0.005	1	0.005	0.002	0.965
WDIR	2.330	1	2.330	0.831	0.362
WSPD* WDIR	4.695	1	4.695	1.675	0.196

ICETRAN	0.298	1	0.298	0.106	0.745
WAVETRAN	19.075	1	19.075	6.805	0.009
HABITAT	47.270	4	11.818	4.216	0.002
AREA	0.000	1	0.000	0.000	0.989
YEAR* AREA	0.328	1	0.328	0.117	0.732
HABITAT* DAYTRAN	26.627	4	6.657	2.375	0.051
HABITAT* TIME	152.752	4	38.188	13.623	0.000
HABITAT* WSPD	22.485	4	5.621	2.005	0.093
HABITAT* WDIR	10.221	4	2.555	0.912	0.457
HABITAT* WAVETRAN	26.491	4	6.623	2.362	0.052
HABITAT* ICETRAN	25.971	4	6.493	2.316	0.057
ERROR	1213.824	433	2.803		

Appendix 3. SYSTAT multiple regressicm analysis output for the oldsquaw molt period (15 July to 21 August 1977-1984 and 1989) in the central Alaska Beaufort Sea.

```
>USE 'HD84:Applications:Statistics:Systat Modules:moltxt'
VARIABLES IN SYSTAT FILE ARE:

     DENS      DENSTRAN       YEAR        DAY       TIME
    DEPTH      DEPTRAN    WESTEAST   WESTRAN       DIST
  D1STRAN         WSPD        WDIR    ORDWND   ORDWTRAN
  NCOMWND     NECOMWND         ICE   ICETRAN     WAVEHT
  DAYTRAN     WSPDTRAN    WAVETRAN   HABITAT       AREA
>CATEGORY HABITAT=5
>CATEGORY AREA=2
>MODEL DENSTRAN=CONSTANT+YEAR+DAY+DAYTRAN+TIME+WESTEAST+WSPD+WDIR+WSPD*WDIR+,
> ICETRAN+WAVETRAN+HABITAT+AREA+YEAR*AREA+HABITAT*DAYTRAN+HABITAT*TIME+,
>HABITAT*WSPD+HABITAT*WDIR+HABITAT*WAVETRAN+HABITAT*ICETRAN
>PRINT LONG
>ESTIMATE
```

```
SYSTAT VERSION 3.2     COPYRIGHT, 1988 SYSTAT, INC.
YOU ARE IN HGLH MODULE

DEP VAR:DENSTRAN      N:   275     MULTIPLE R:   .825     SQUARED MULTIPLE R:   .681
                                         -1
ESTIMATES OF EFFECTS B = (X'X) X'Y)

                    DENSTRAN

CONSTANT                 -1.269

    YEAR                 -0.076

     DAY                  0.099

 DAYTRAN                 -0.001

    TIME                  0.001

WESTEAST                 -0.128

    WSPD                 -0.025

    WDIR                 -0.007

    WSPD
    WDIR                  0.000

 ICETRAN                  0.374

WAVETRAN                 -0.457

 HABITAT        1        -1.645

 HABITAT        2         3.244

 HABITAT        3         2.415

 HABITAT        4         3.258

    AREA        1        -1.121

    YEAR
    AREA        1         0.153

 HABITAT        1
 DAYTRAN                  0.000

 HABITAT        2
 DAYTRAN                  0.000

 HABITAT        3
 DAYTRAN                 -0.000

 HABITAT        4
 DAYTRAN                 -0.001

 HABITAT        1
    TIME                  0.002

 HABITAT        2
    TIME                 -0.003

 HABITAT        3
    TIME                  0.001
```

HABITAT	4	
TIME		-0.000
HABITAT	1	
WSPD		0.003
HABITAT	2	
WSPD		0.004
HABITAT	3	
WSPD		0.034
HABITAT	4	
WSPD		-0.077
HABITAT	1	
WDIR		0.003
HABITAT	2	
WDIR		0.003
HABITAT	3	
WDIR		-0.002
HABITAT	4	
WDIR		0.000
HABITAT	1	
WAVETRAN		0.359
HABITAT	2	
WAVETRAN		0.198
HABITAT	3	
WAVETRAN		-1.030
HABITAT	4	
WAVETRAN		0.210
HABITAT	1	
ICETRAN		-0.322
HABITAT	2	
ICETRAN		1.181
HABITAT	3	
ICETRAN		0.195
HABITAT	4	
ICETRAN		-0.892

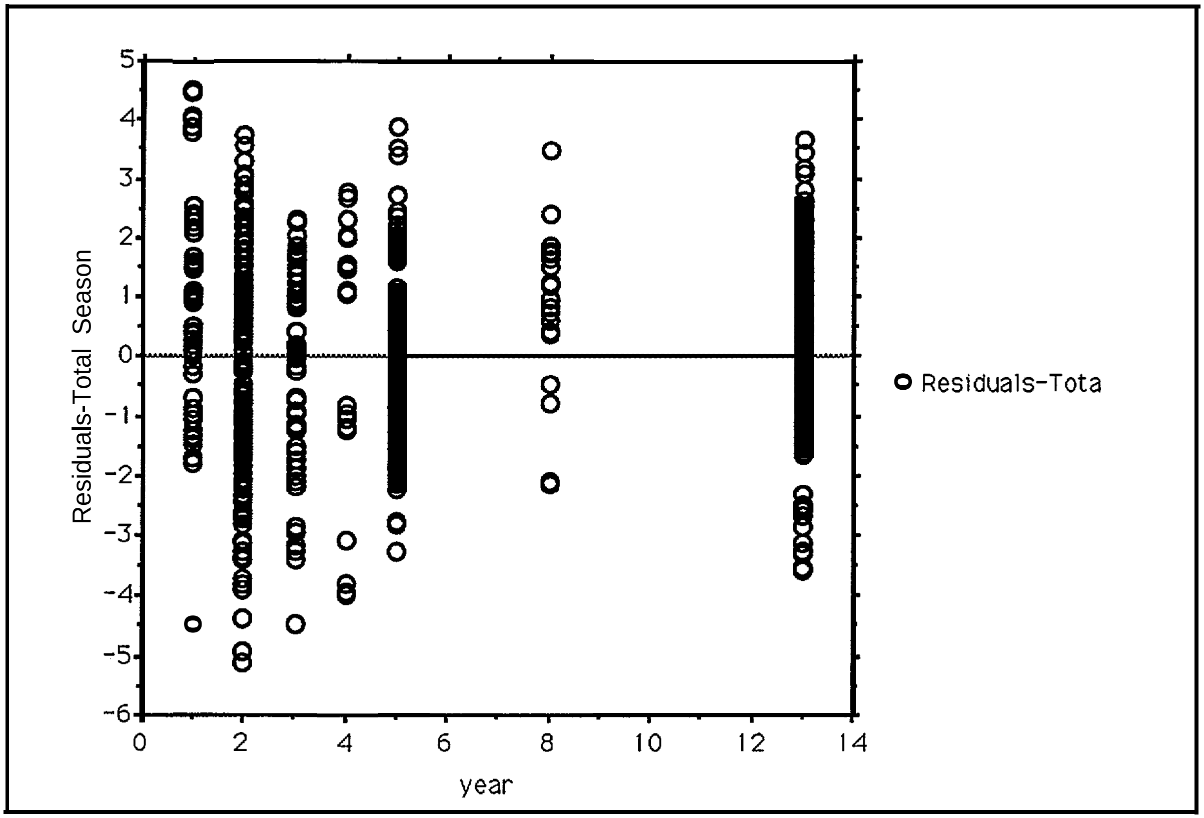
ANALYSIS OF VARIANCE

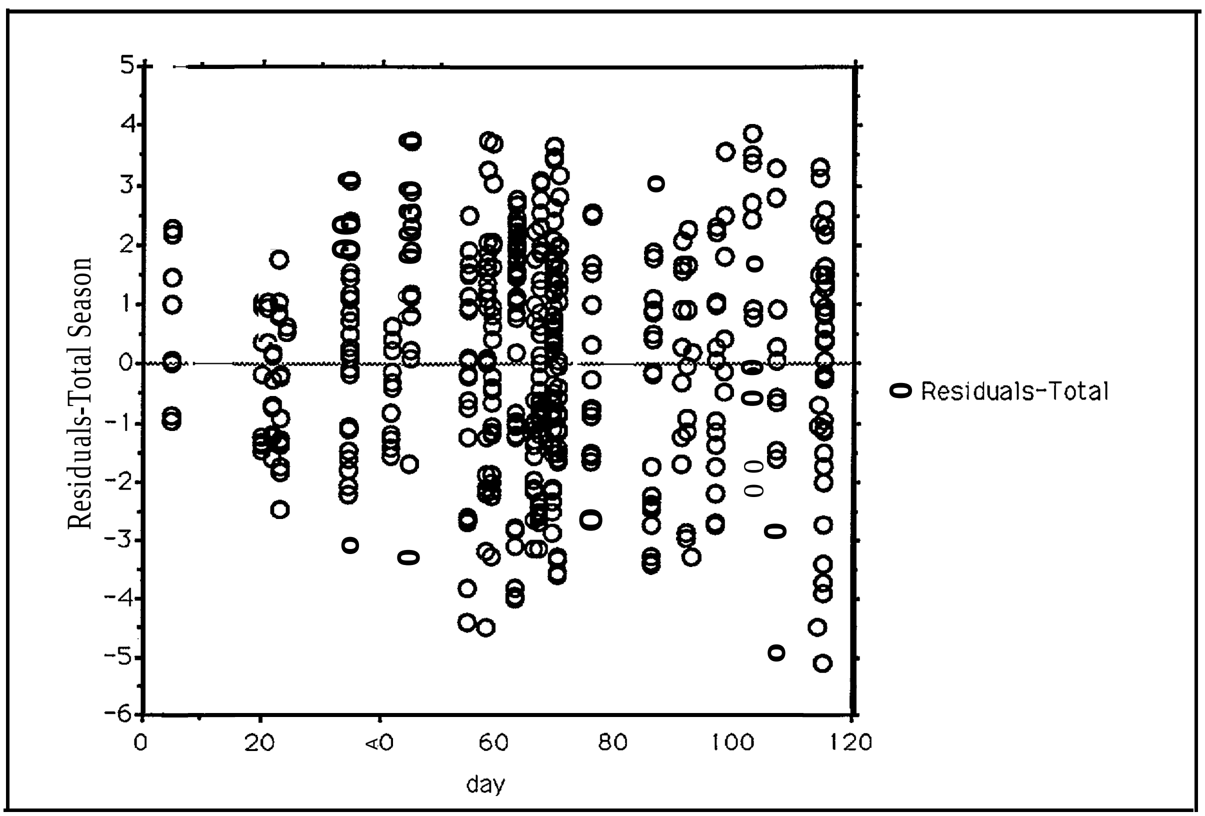
SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
YEAR	8.389	1	8.389	3.303	0.070
DAY	0.438	1	0.438	0.172	0.678
DAYTRAN	0.209	1	0.209	0.082	0.774
TIME	3.410	1	3.410	1.343	0.248
WESTEAST	4.807	1	4.807	1.893	0.170
WSPD	0.434	1	0.434	0.171	0.680
WDIR	7.266	1	7.266	2.861	0.092
WSPD* WDIR	18.892	1	18.892	7.439	0.007

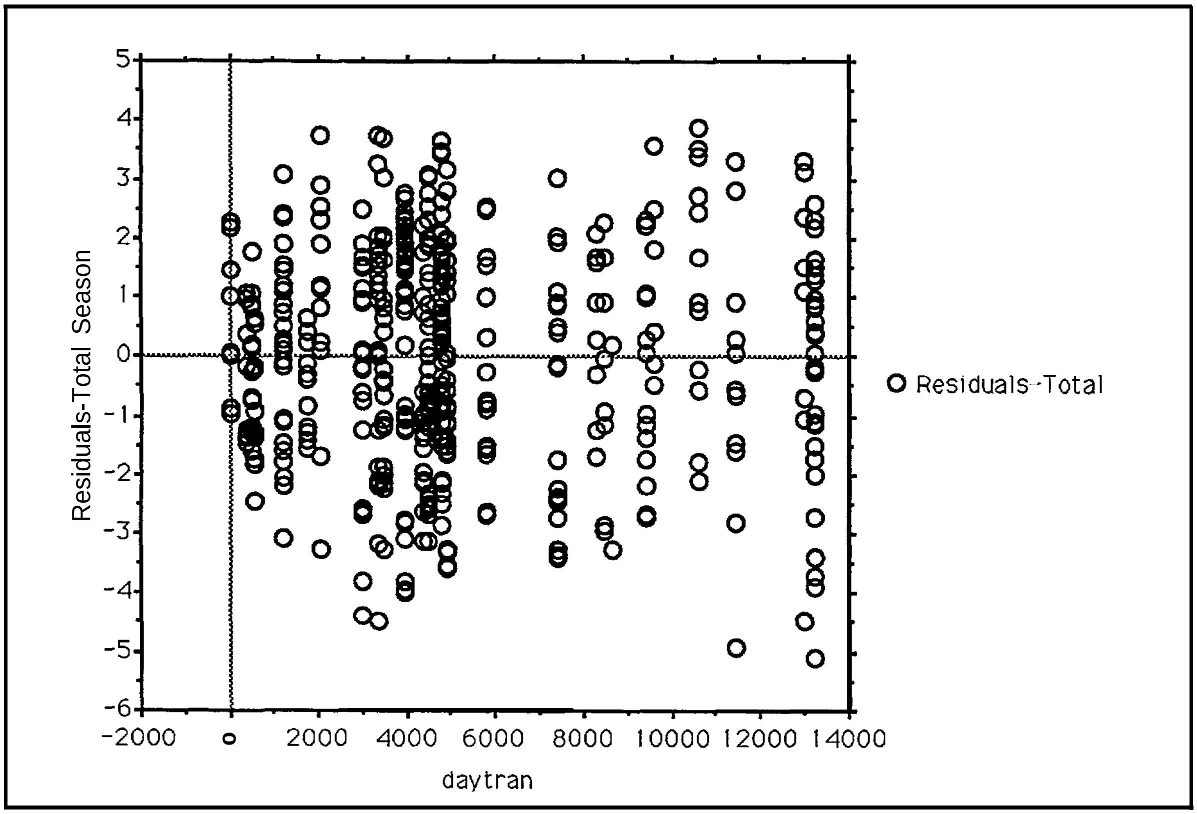
ICETRAN	3.844	1	3.844	1.514	0.220
WAVETRAN	16.841	1	16.841	6.632	0.011
HABITAT	16.045	4	4.011	1.580	0.180
AREA	3.511	1	3.511	1.383	0.241
YEAR* AREA	18.685	1	18.685	7.358	0.007
HABITAT* DAYTRAN	12.228	4	3.057	1.204	0.310
HABITAT* TIME	74.523	4	18.631	**7.336**	0.000
HABITAT* WSPD	14.635	4	3.659	1.441	0.221
HABITAT* WDIR	6.766	4	1.692	0.666	0.616
HABITAT* WAVETRAN	11.790	4	2.947	1.161	0.329
HABITAT* ICETRAN	37.145	4	9.286	3.657	0.007
ERROR	594.237	234	2.539		

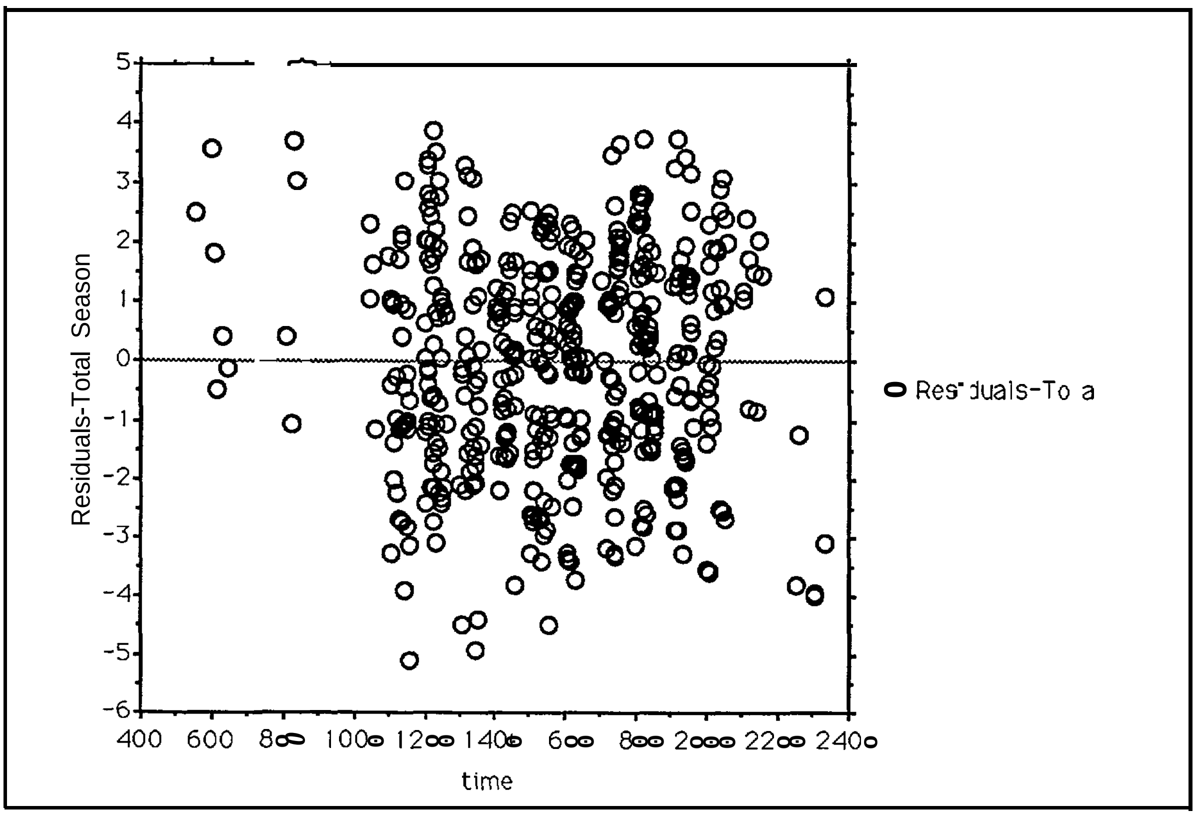
Appendix 4. Plots of multiple regression residuals vs. the various independent variables used in the complete season (5 June to 23 September 1977-1984 and 1989) and molt period (15 July to 21 August 1977-1984 and 1989) multiple regression analyses.

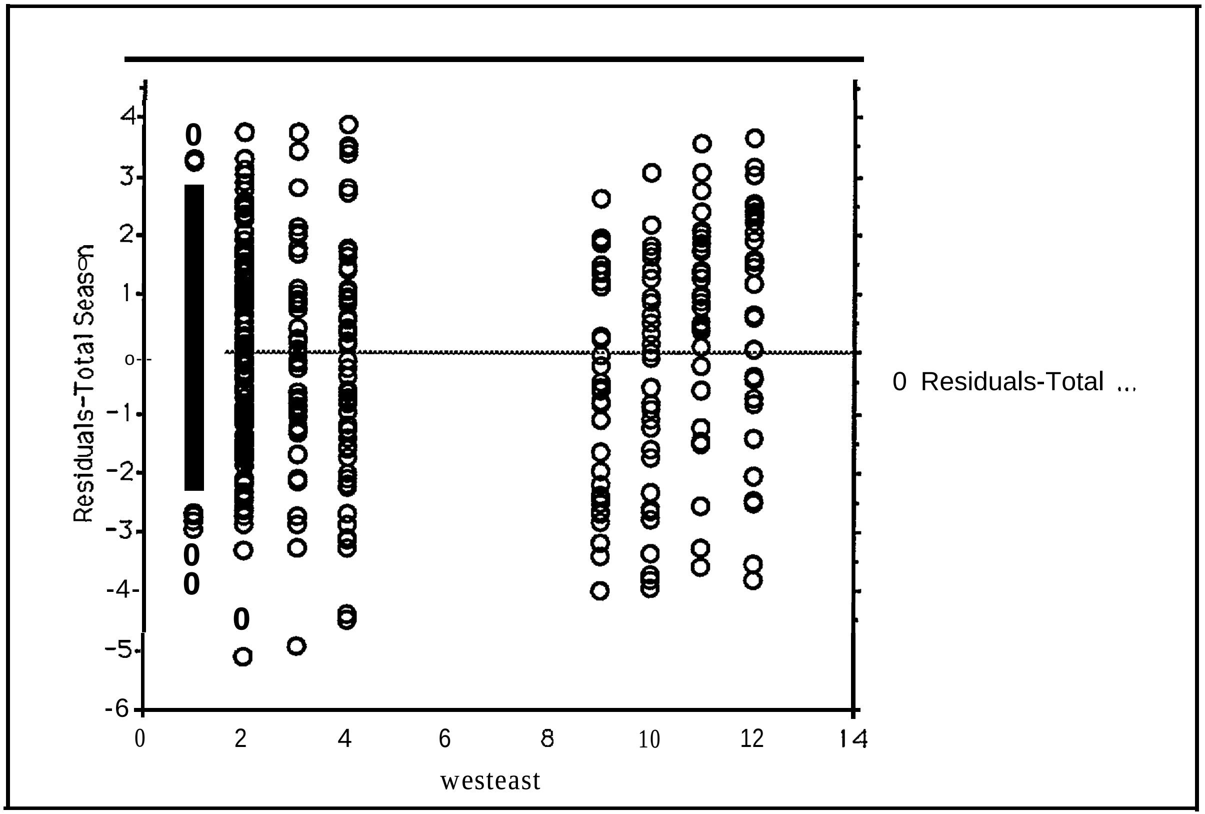
Appendix 4

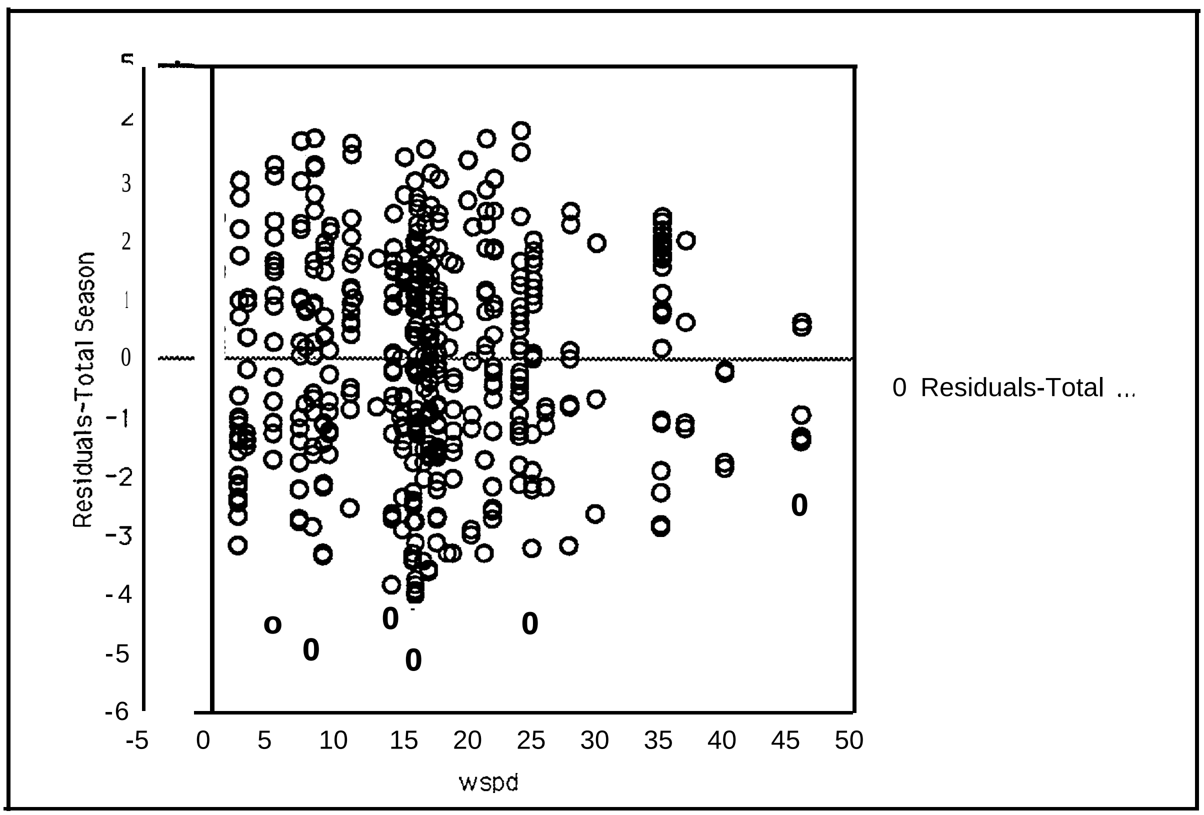

Residuals-Total Season
year
Residuals-Tota

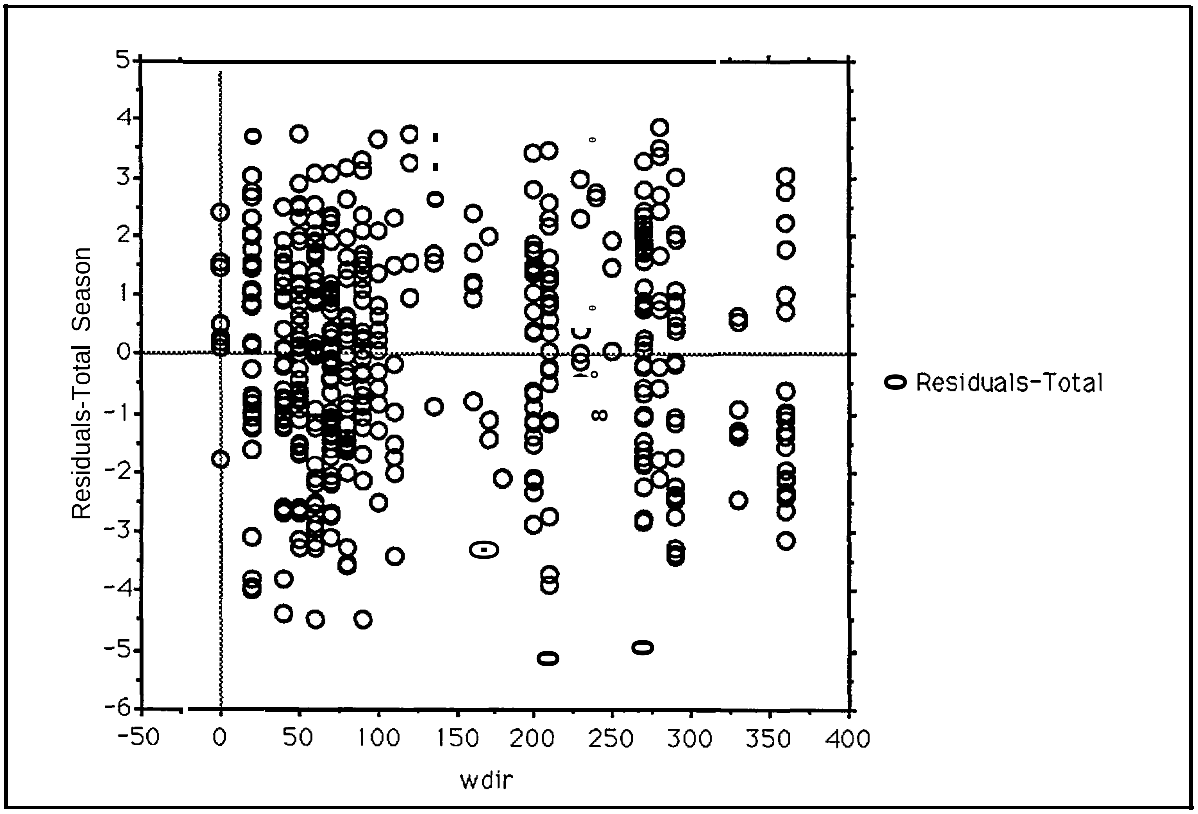

Residuals-Total Season
day
Residuals-Total

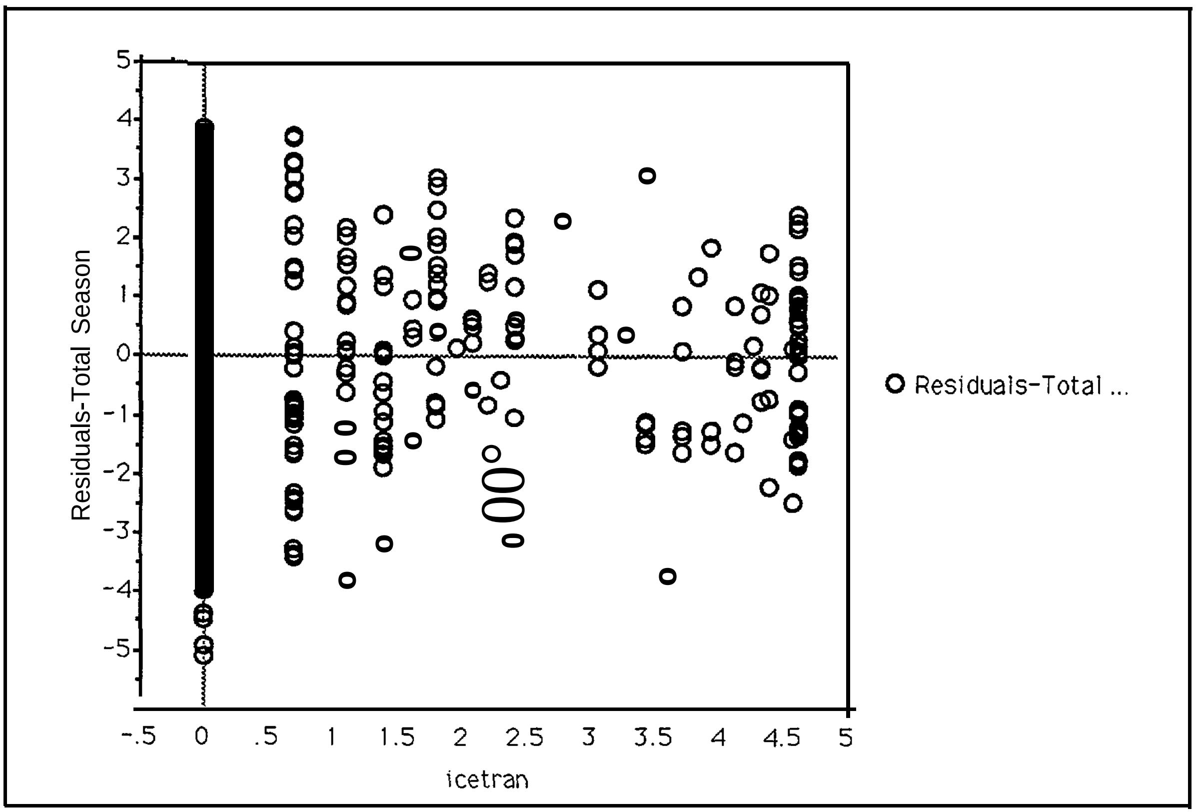

Residuals-Total Season
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-2000
0
2000
4000
6000
8000
10000
12000
14000
daytran
Residuals-Total

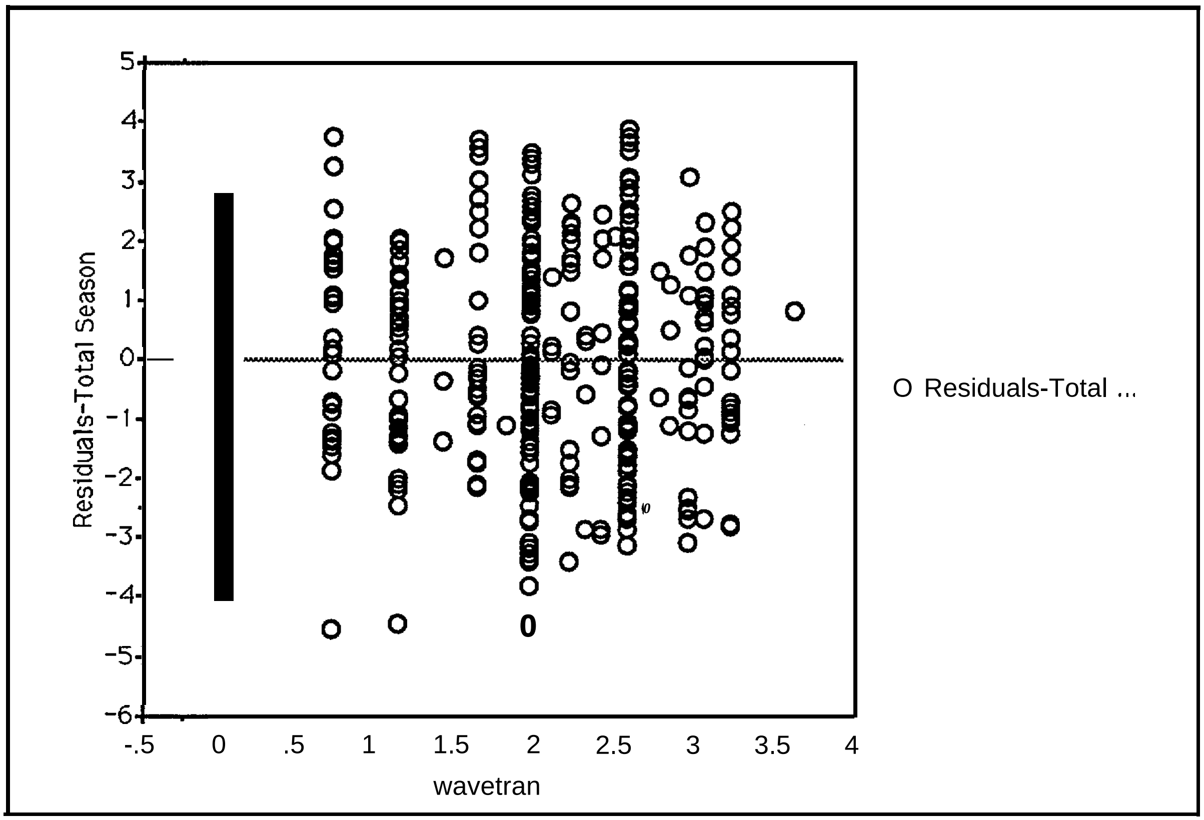

Residuals-Total Season
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
400
600
time
Res'duals-To a

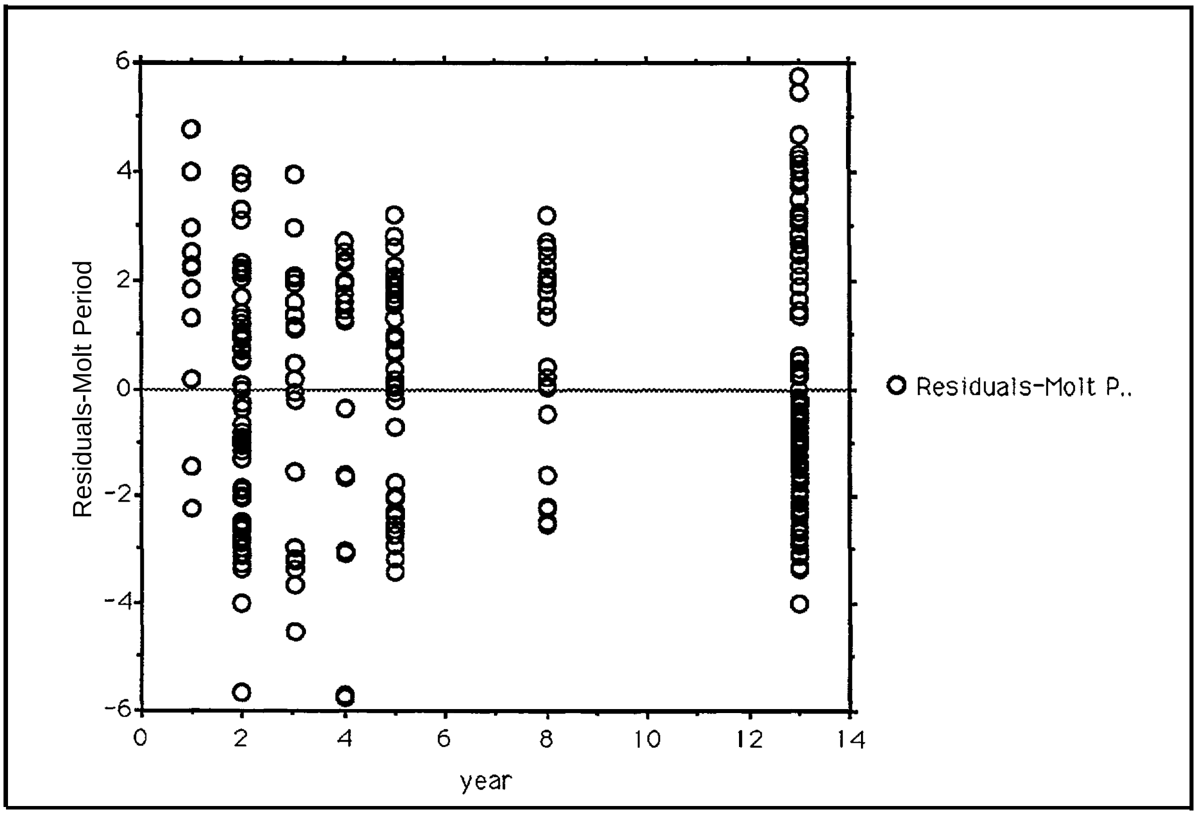

Residuals-Total Season
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
2
4
6
8
10
12
14
westeast
0 Residuals-Total ...

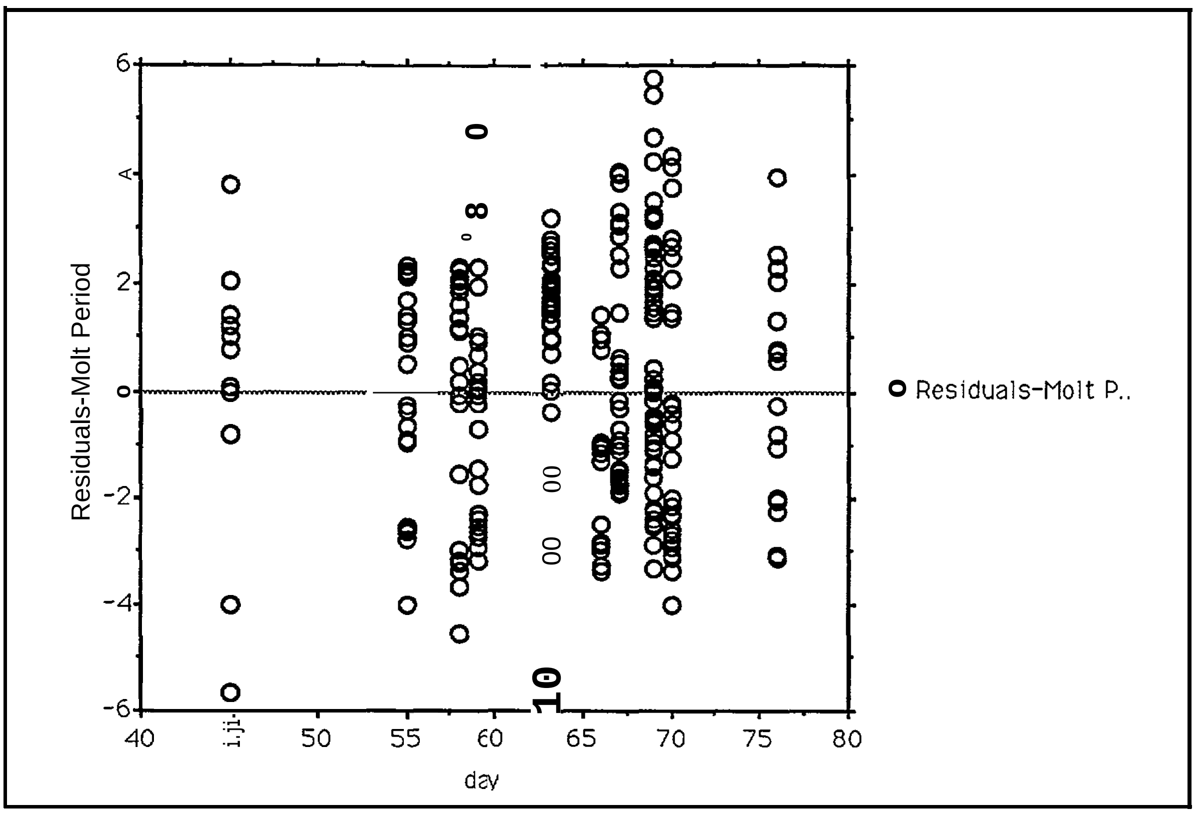

Residuals-Total Season
3
2
1
0
-1
-2
-3
-4
-5
-6
-5
0
5
10
15
20
25
30
35
40
45
50
wspd
0 Residuals-Total ...

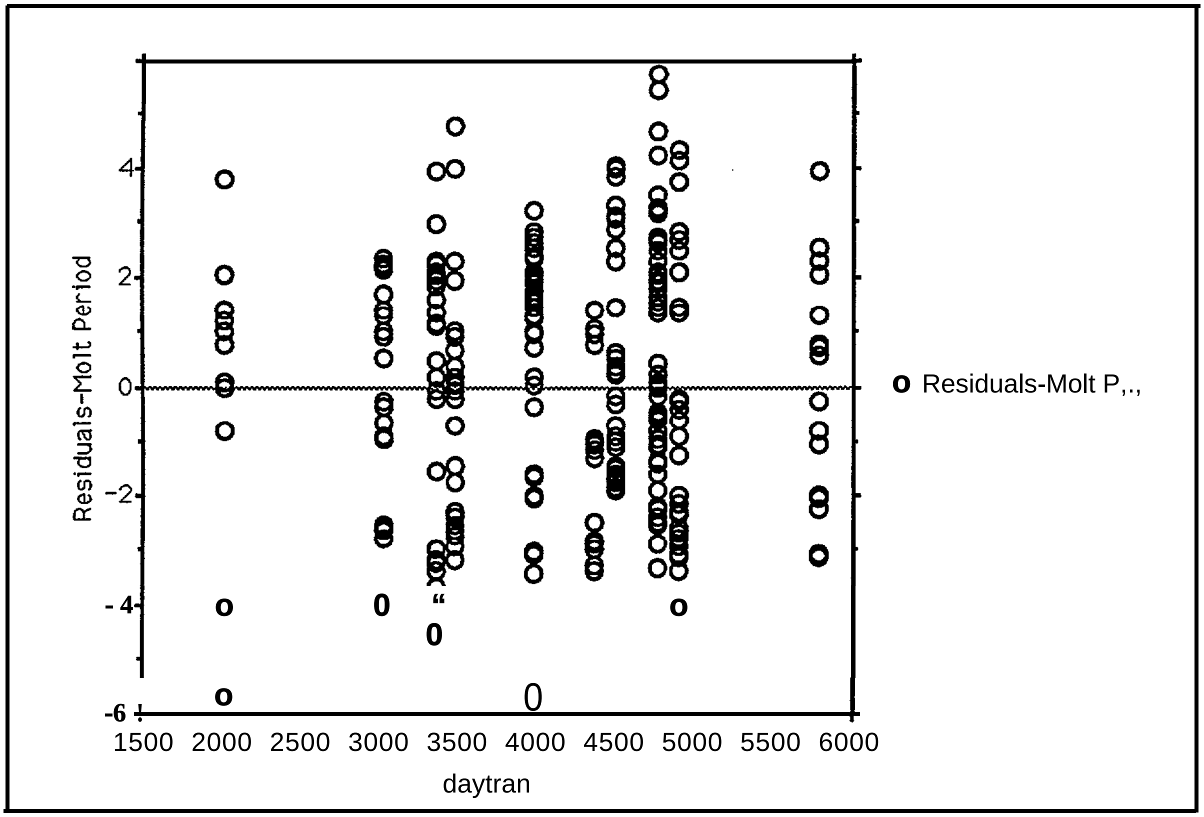

Residuals-Total Season
wdir
Residuals-Total

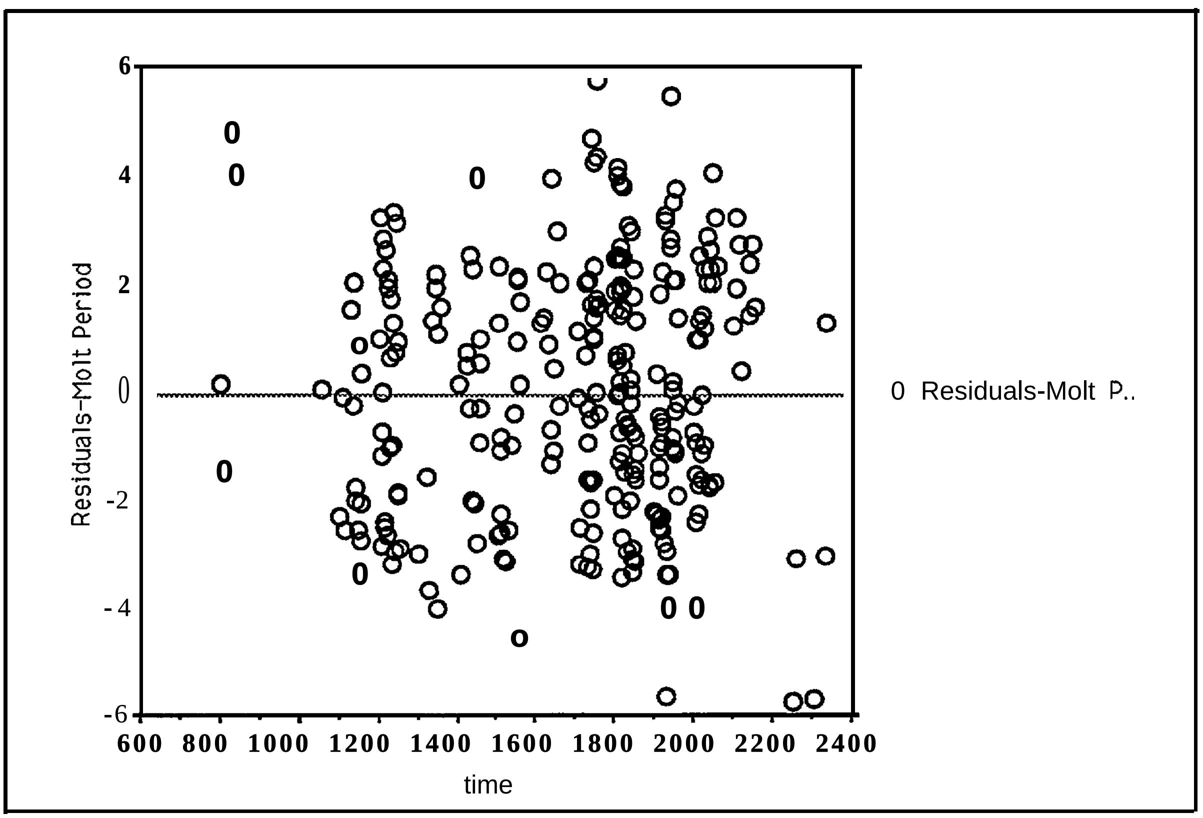

Residuals-Total Season
icetran
Residuals-Total ...

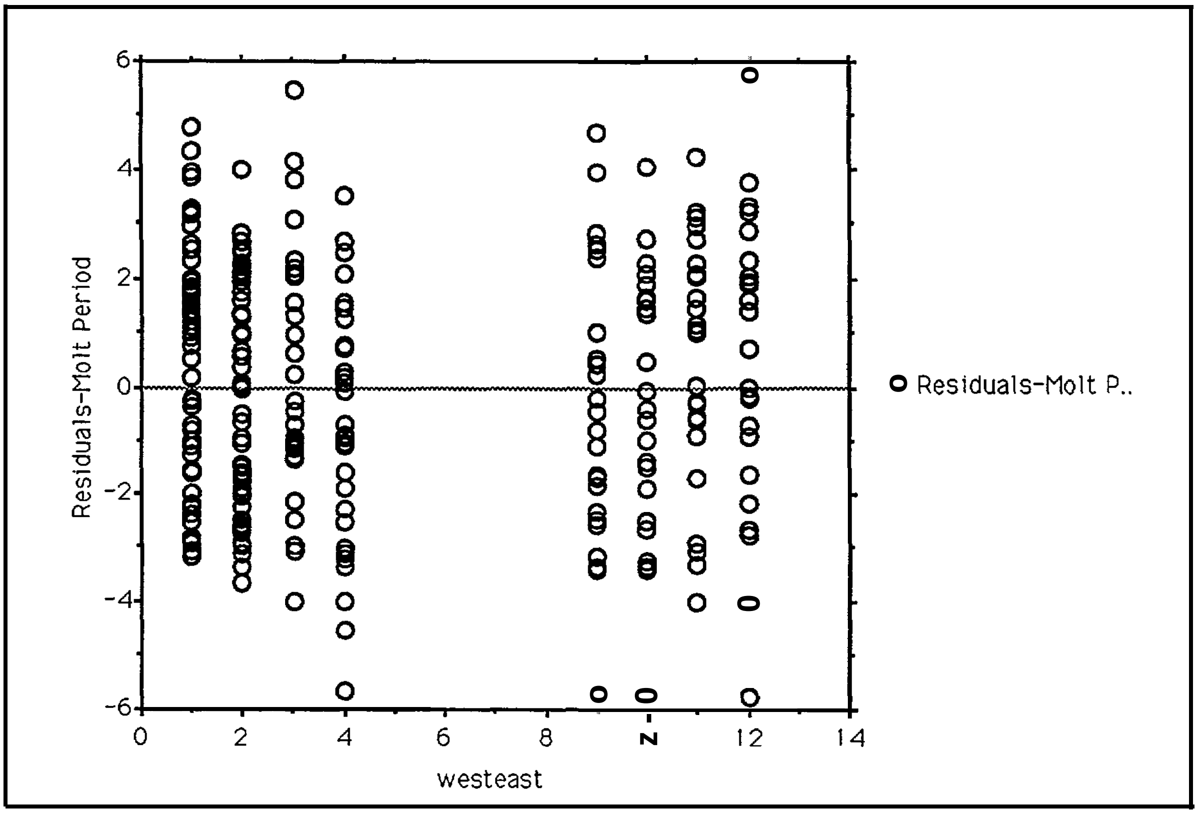

Residuals-Total Season
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-.5
0
.5
1
1.5
2
2.5
3
3.5
4
wavetran
O Residuals-Total ...

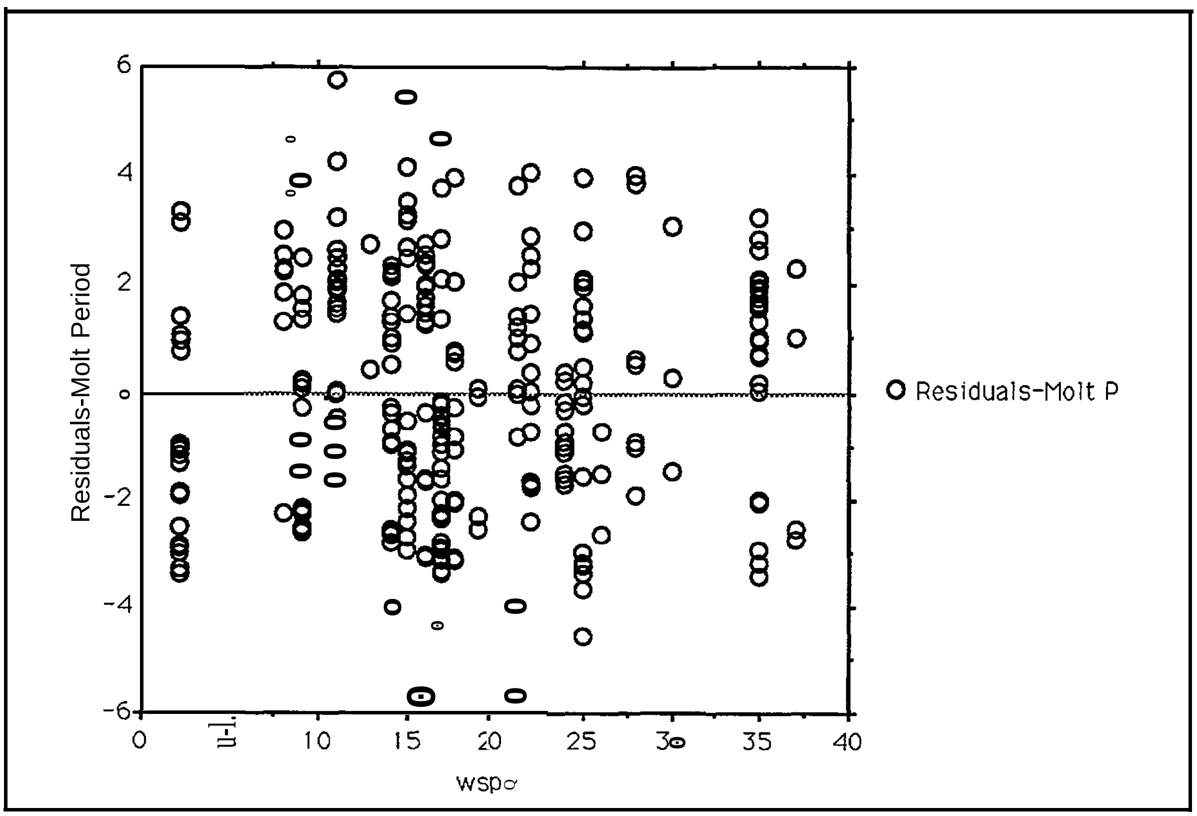

Residuals-Molt Period
year
Residuals-Molt P..

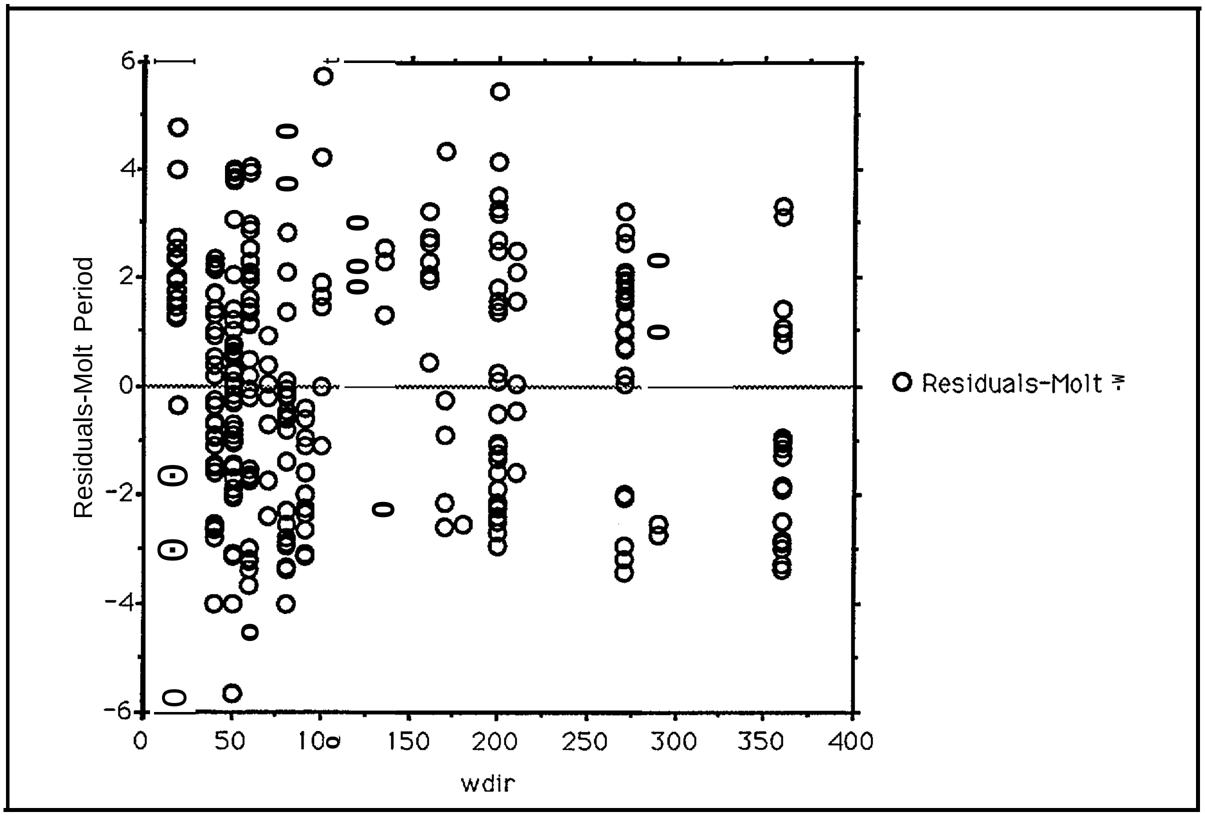

Residuals-Molt Period
day
Residuals-Molt P..

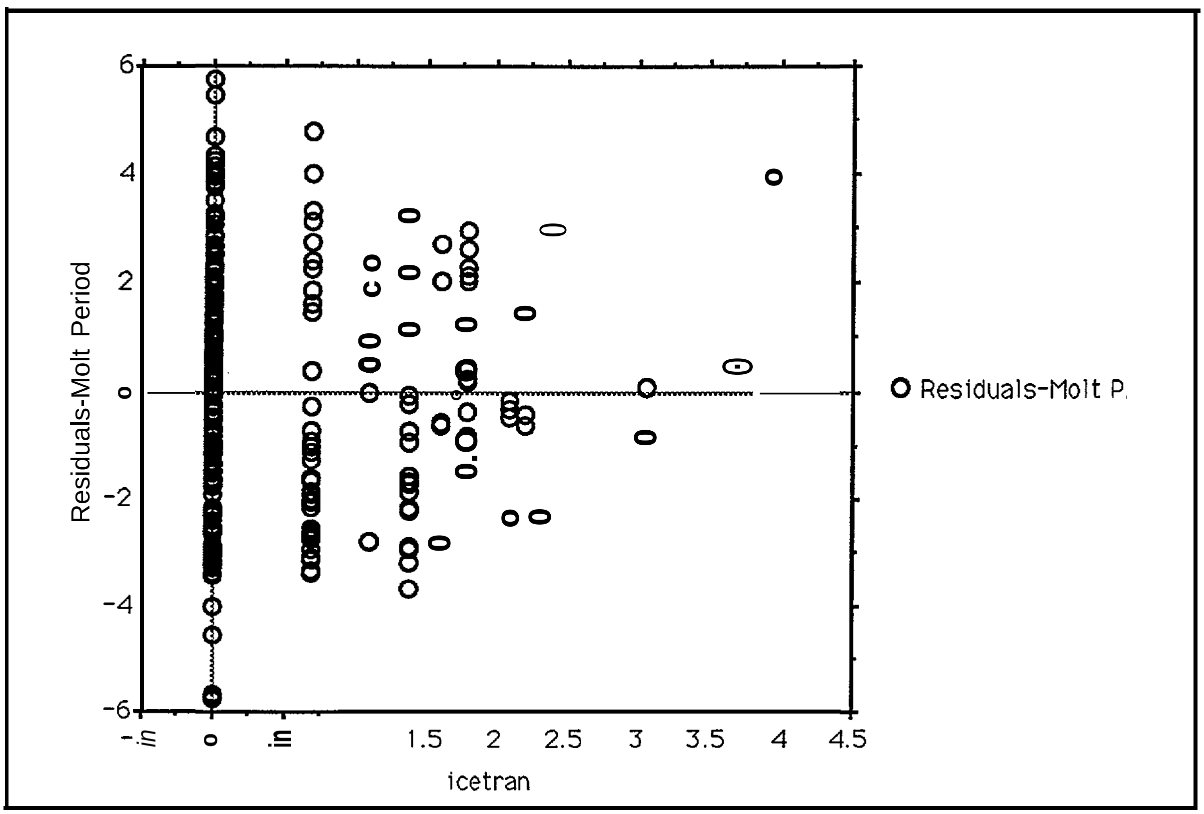

Residuals-Molt Period
daytran
1500 2000 2500 3000 3500 4000 4500 5000 5500 6000
o Residuals-Molt P,.,

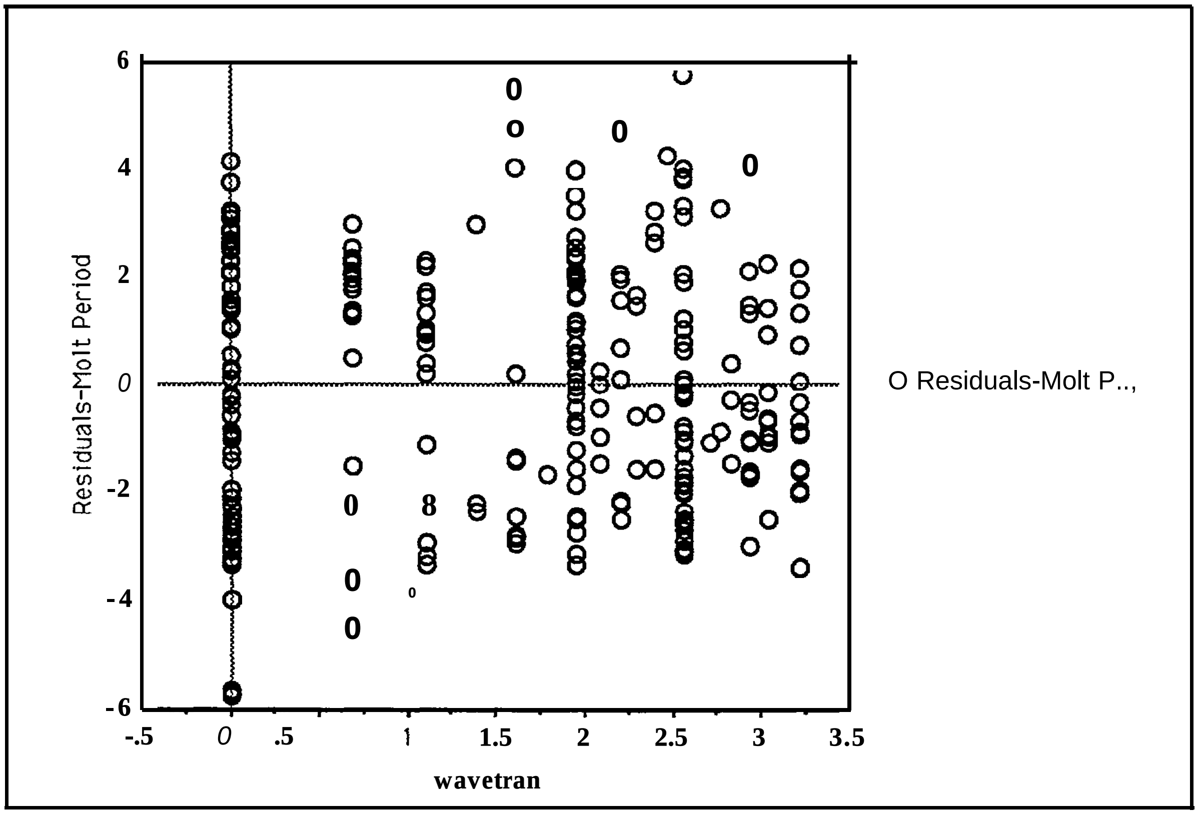

Residuals-Molt Period
time
600 800 1000 1200 1400 1600 1800 2000 2200 2400
0 Residuals-Molt P..


Residuals-Molt Period
westeast
Residuals-Molt P..


Residuals-Molt Period
wspd
Residuals-Molt P


Residuals-Molt Period
wdir
Residuals-Molt


Residuals-Molt Period
icetran
Residuals-Molt P.



Residuals-Molt Period
6
4
2
0
-2
-4
-6
-.5
0
.5
1
1.5
2
2.5
3
3.5
wavetran
O Residuals-Molt P..,

Appendix 5. Disturbance codes assigned to transects in the Industrial and Control study areas in 1990 and 1991. Code 1 cases (no known disturbance) are not listed.

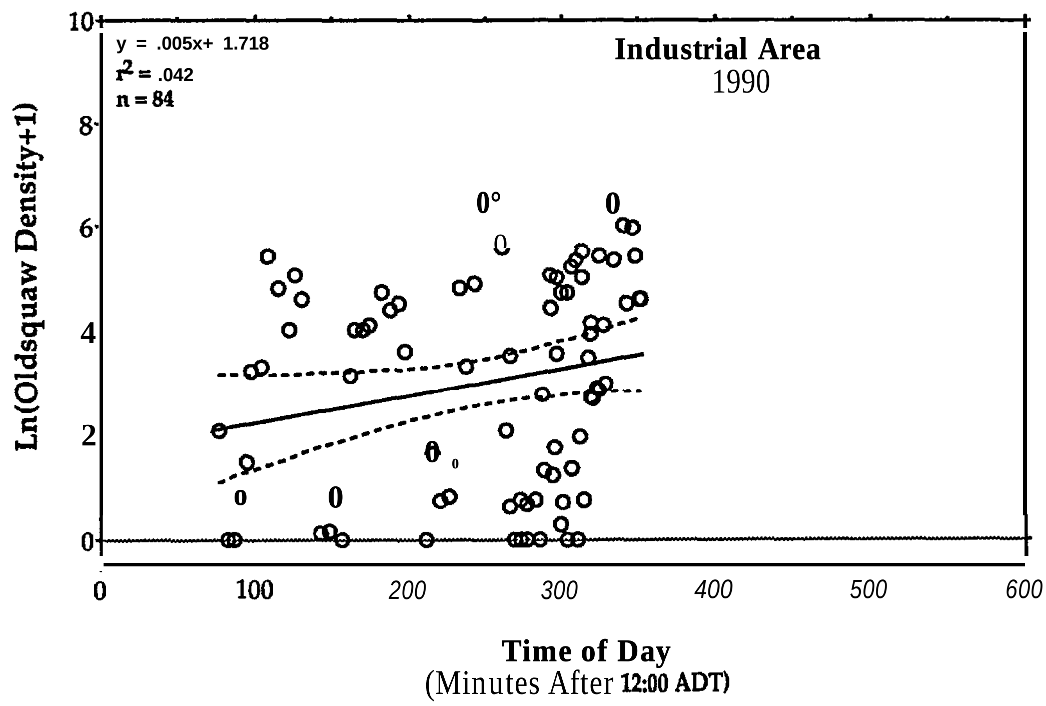
Potential Disturbance Level	Date	Study Area*	Transect Number	Activity Recorded
3	20 Jul 1990	I	33	Five boats and 8-10 workers on or adjacent to transect
3	20 Jul 1990	C	183	Two seismic ships and three support vessels on transect
3	23 Jul 1990	I	25	Five boats and 8-10 workers on or adjacent to transect
3	23 Jul 1990	c	192	Two seismic ships and three support vessels on transect
3	02 Aug 1990	I	32	Six boats on transect, several aircraft overflights
3	04 Aug 1990	I	2s	Six boats and 10-12 workers on or adjacent to transect
3	04 Aug 1990	I	24	Six boats on transect, several aircraft overflights
3	09 Aug 1990	C	133	Two seismic ships and three support vessels on transect
3	16 Aug 1990	I	25	Six boats and 10-12 workers on or adjacent to transect
3	16 Aug 1990	I	23	Six boats and 10-12 workers on or adjacent to transect
2	20 Jul 1990	I	32	Two boats on transect
2	20 Jul 1990	C	193	One boat on transect
2	23 Jul 1990	I	24	Two boats on transect
2	03 Aug 1990	I	33	One boat on transect
2	03 Aug 1990	I	301	Two boats on transect
2	04 Aug 1990	C	193	One boat on transect
2	09 Aug 1990	C	182	One seismic ship on transect
2	16 Aug 1990	I	24	Two boats on transect
2	20 Aug 1990	I	401	Two boats on transect
2	20 Aug 1990	I	25	One boat at net on transect
2	20 Aug 1990	I	23	Two ships on transect
2	20 Aug 1990	r	22	One ship on transect
2	04 Aug 1991	C	192	One seismic ship on transect
2	21 Aug 1991	I	22	Tug with two barges on transect
2	21 Aug 1991	I	30	One boat at net on transect

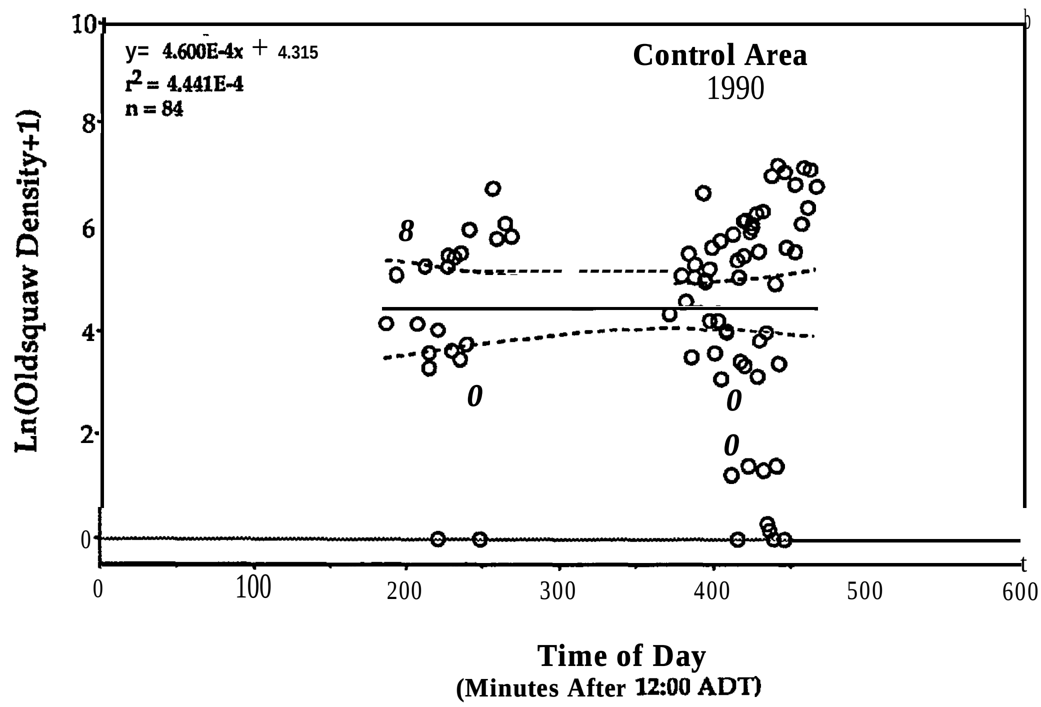
" I = Industrial area, C = Control area

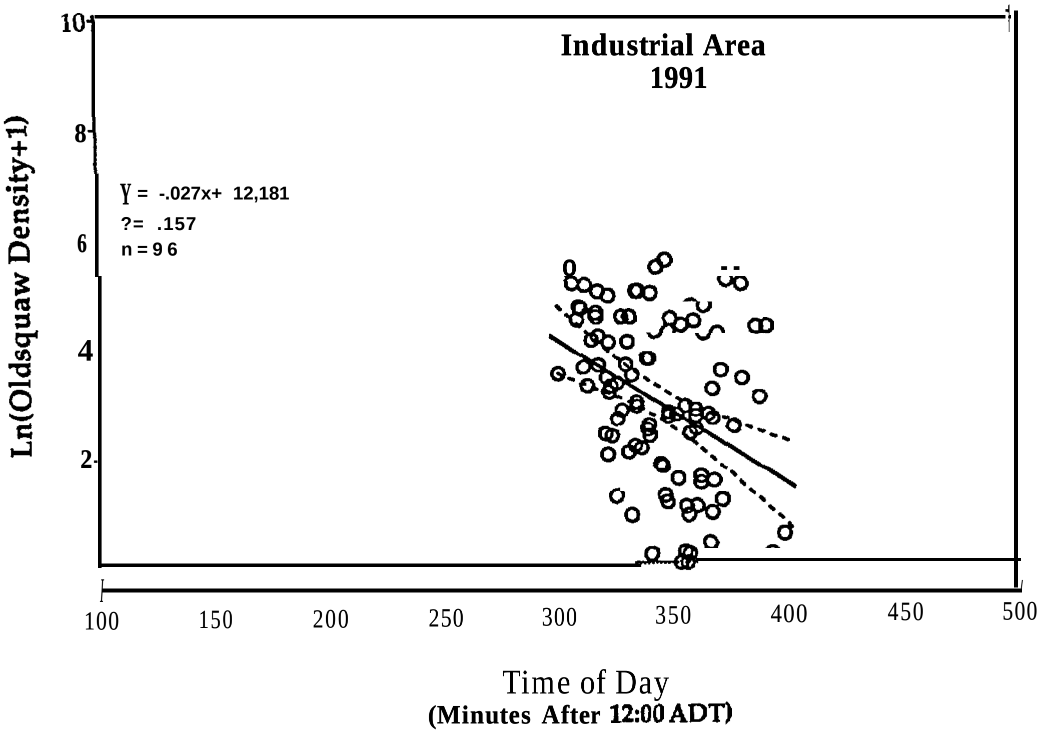
Appendix 6. Relationships between transformed oldsquaw density, Ln(Oldsquaw Density+ l), on transects in the Industrial and Control study areas in 1990 and 1991 vs. time of day, transformed wave height, disturbance, transformed day of season, transect location (W-E), transformed wind direction, and wind speed (Appends. 6A-6G).

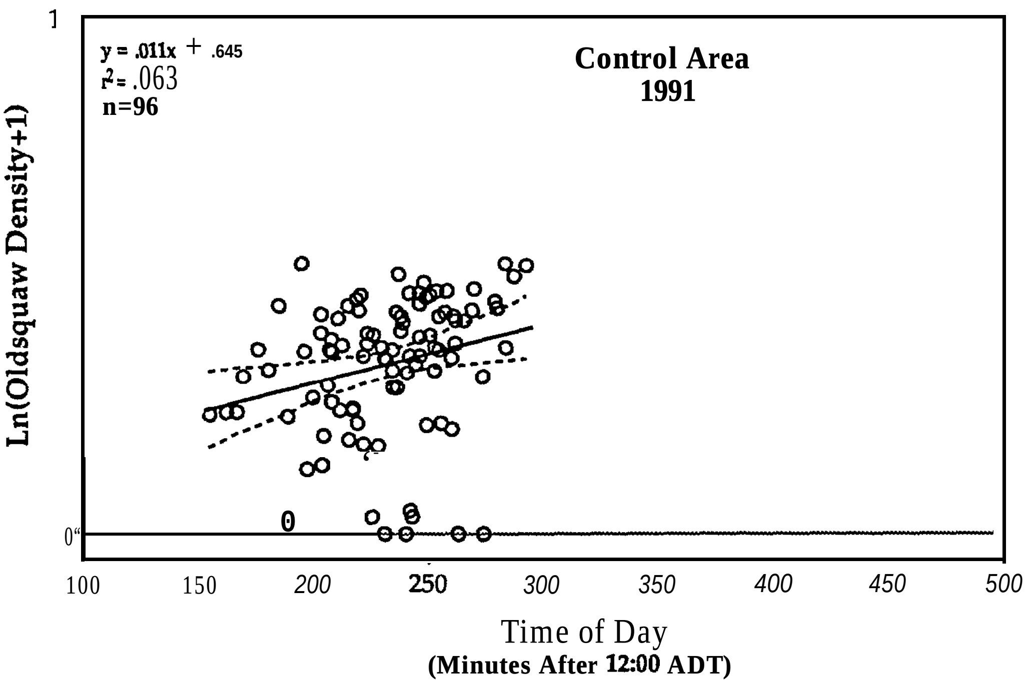
Except for 'time of day' in 1991 (Append. 6A), all relationships between oldsquaw density in Industrial and Control study areas and factors such as wave height, day of season, wind speed and wind direction were consistent with results of earlier studies (summarized earlier in this report and in Johnson 1990). The relationship between oldsquaw density and time of day in 1990 was also similar to past results (positive correlation, Johnson 1990), but oldsquaw density vs. time of day in 1991 showed an unusual negative correlation in the Industrial area, suggesting either a spurious correlation or unusual behavior by the birds over the relatively short time-period during which surveys were conducted in 1991. Past results have shown positive correlations between time of day and oldsquaw density, especially when surveys were conducted without regard for time of day, i.e., over a relatively broad range of times throughout the day. In this study we recommended that all oldsquaw surveys be conducted as expeditiously as possible, and as late in the day as feasible, in order to obtain peak counts of birds and to reduce possible temporal influences on survey results. All surveys in this study were conducted well after mid-day, and most surveys, especially in the Industrial study area in 1991, were conducted two to seven hours after mid-day (150-400 minutes after 12:00 ADT)(Append. 6A). Given these circumstances, the results of analyses of oldsquaw density vs. time of day from surveys in the Industrial area in 1991 are not readily explainable.

Appendix 6A. Relationship between *oldsquaw density and time of day* in the Industrial and Control study areas in 1990 and 1991.

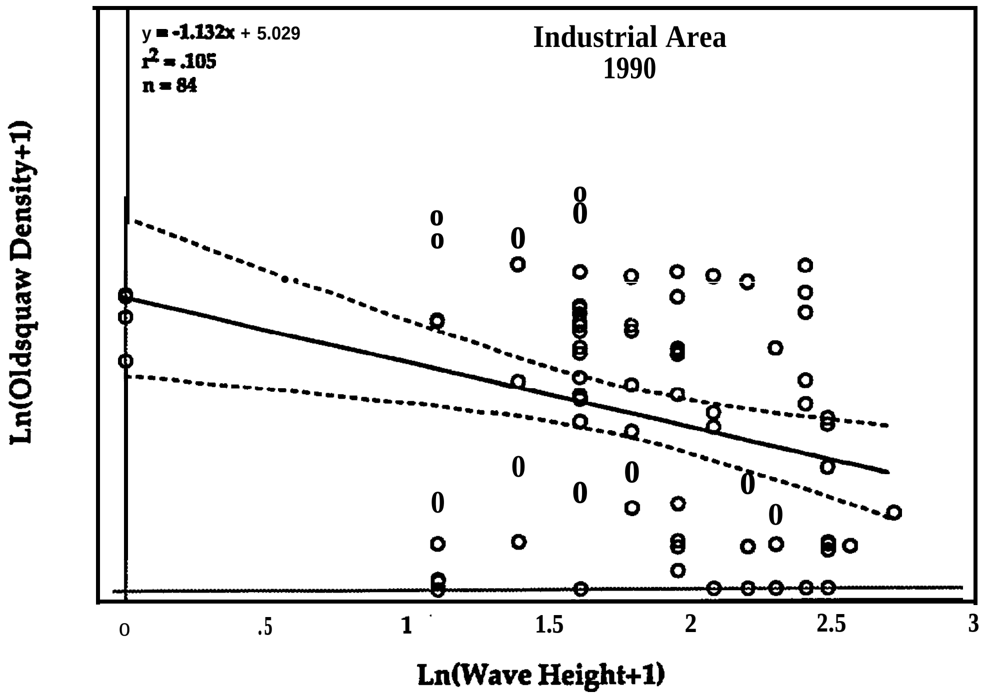


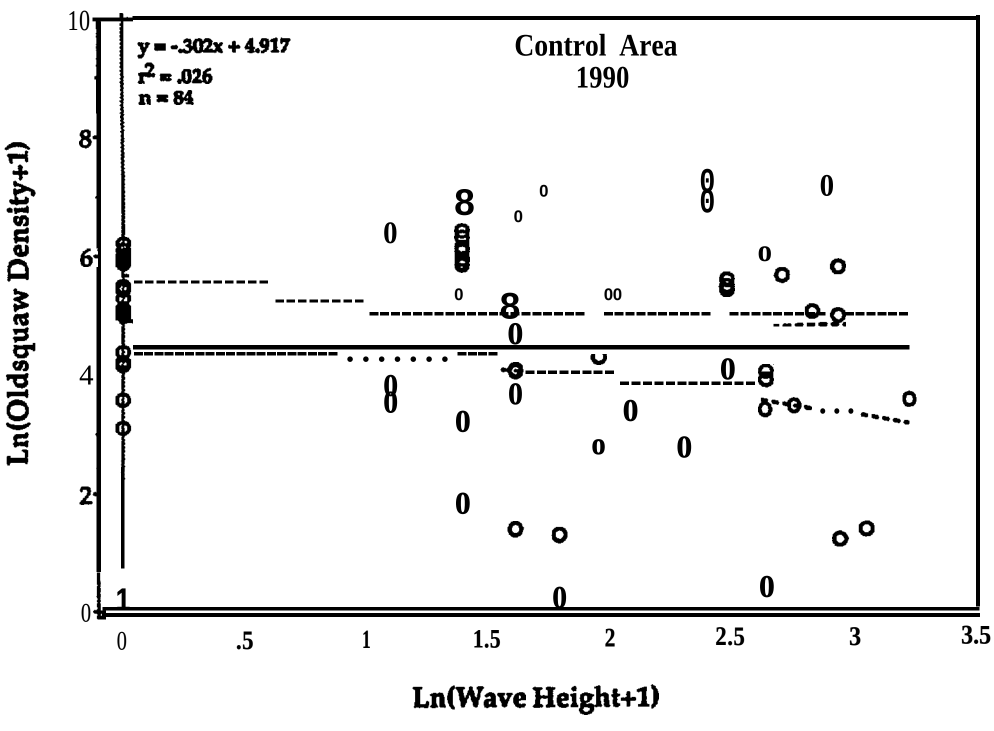


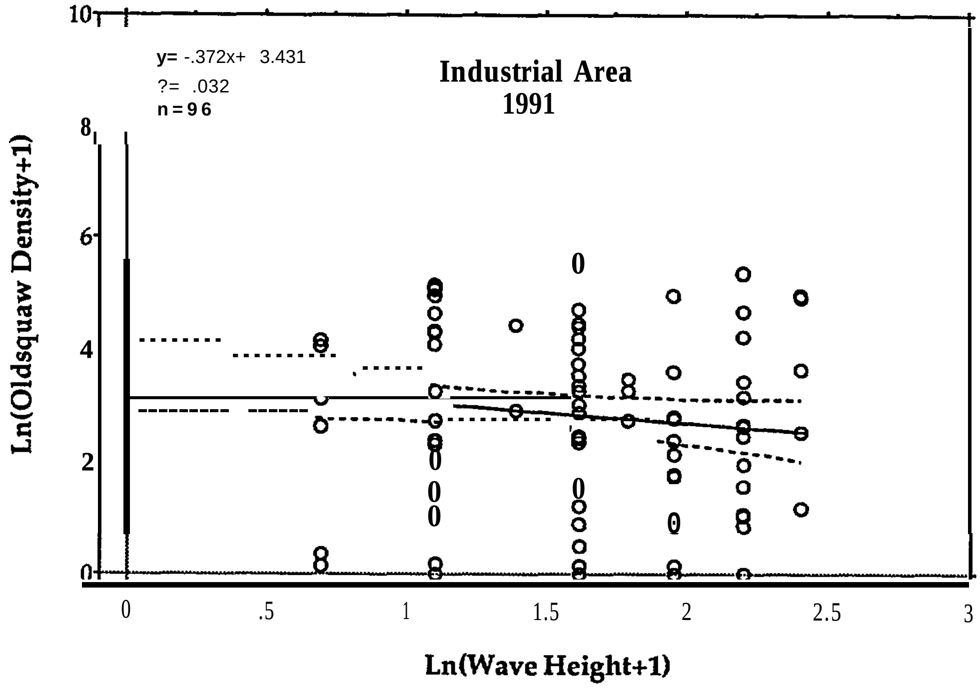

Industrial Area
1991
Y = -.027x+ 12,181
?= .157
n = 9 6
Ln(Oldsquaw Density+1)
10
8
6
4
2
100
150
200
250
300
350
400
450
500
Time of Day
(Minutes After 12:00 ADT)

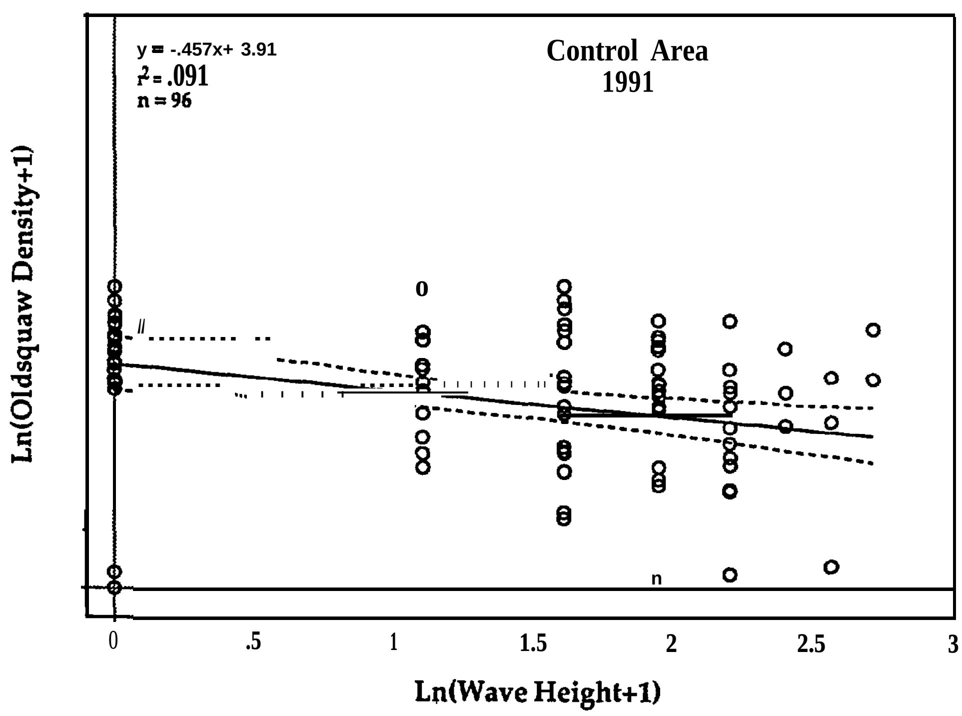

Control Area
1991
y = .011x + .645
r2 = .063
n=96
Ln(Oldsquaw Density+1)
1
0
100
150
200
250
300
350
400
450
500
Time of Day
(Minutes After 12:00 ADT)

Appendix 6B. Relationship between ***oldsquaw*** *density* ***and wave height*** **in the** Industrial and Control study areas in 1990 and 1991.

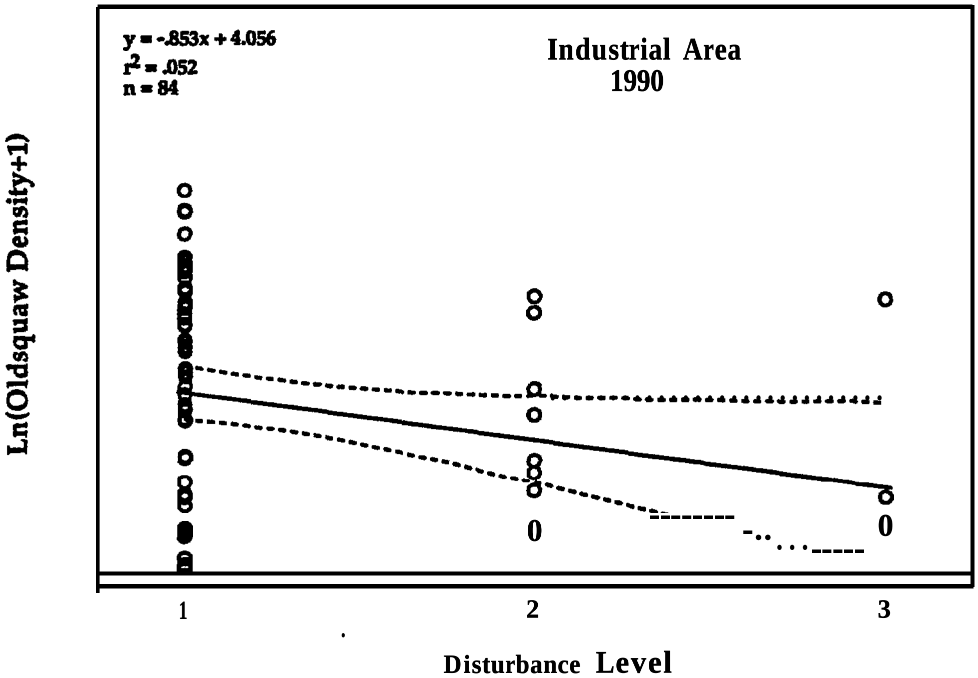


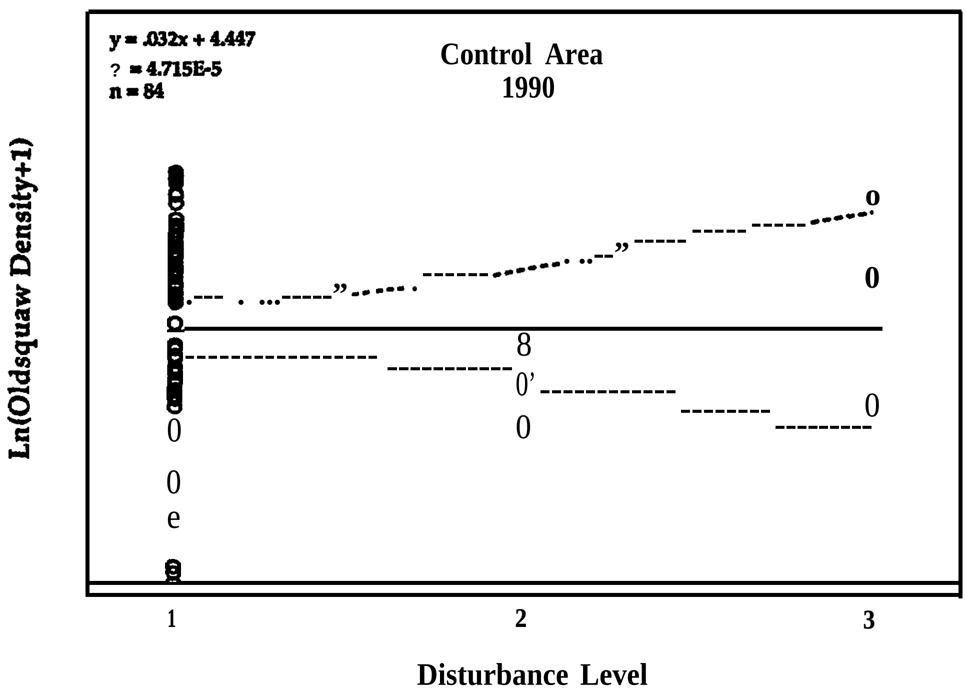


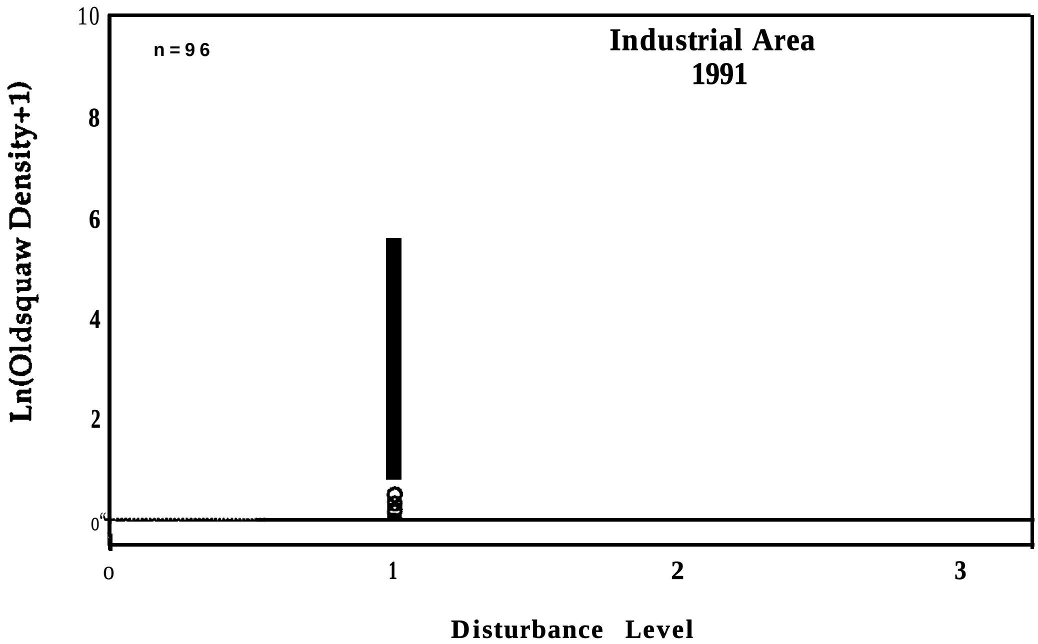

y= -.372x+ 3.431
?= .032
n = 9 6
Industrial Area
1991
Ln(Oldsquaw Density+1)
Ln(Wave Height+1)
10
8
6
4
2
0
0
.5
1
1.5
2
2.5
3


y = -.457x+ 3.91
r² = .091
n = 96
Control Area
1991
Ln(Oldsquaw Density+1)
Ln(Wave Height+1)
0
.5
1
1.5
2
2.5
3

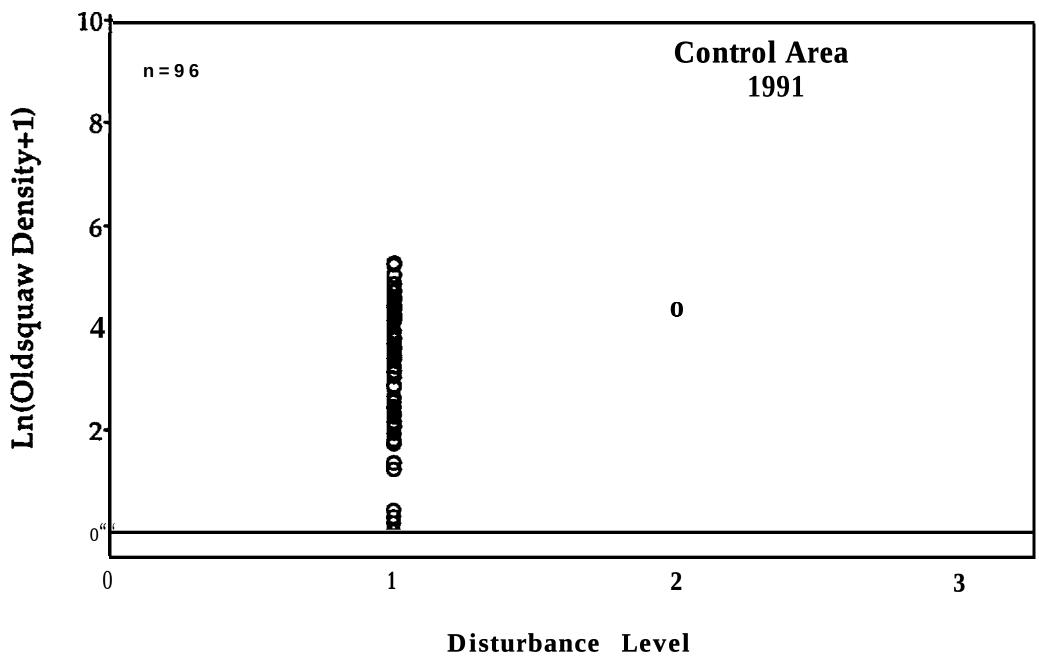
Appendix 6C. Relationship between *oldsquaw density and disturbance level* in the Industrial and Control study areas in 1990 and 1991.





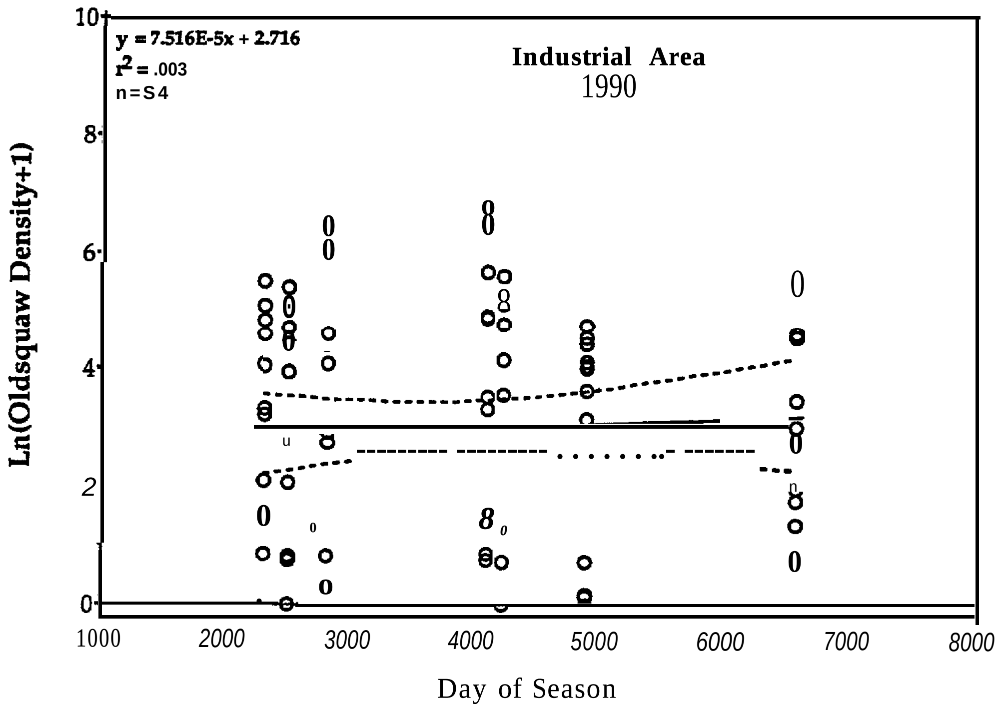


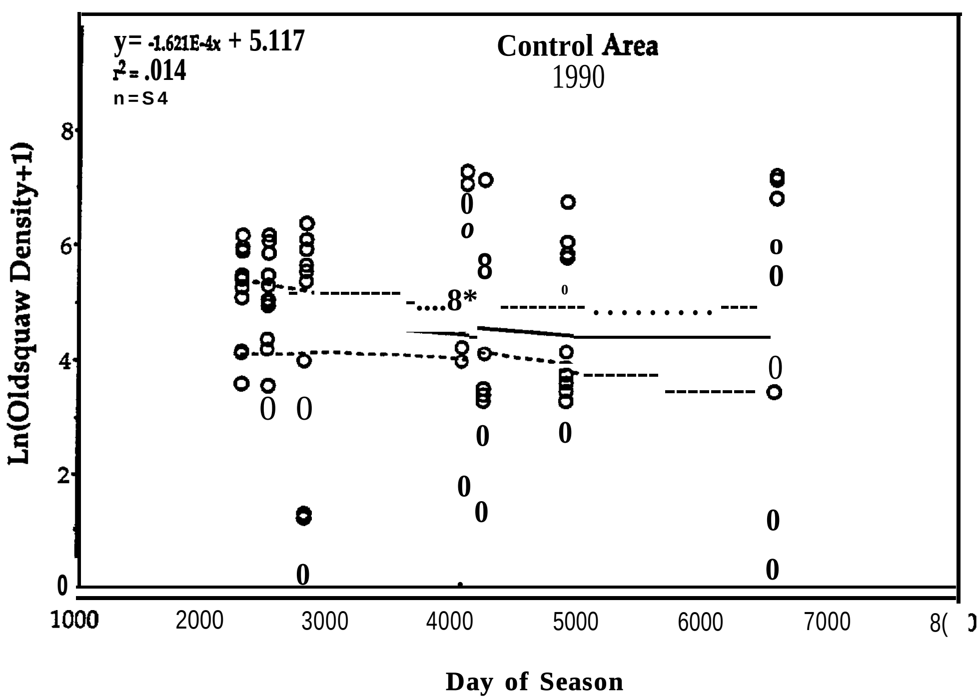
Industrial Area
1991
n = 96
Ln(Oldsquaw Density+1)
10
8
6
4
2
0
0
1
2
3
Disturbance Level

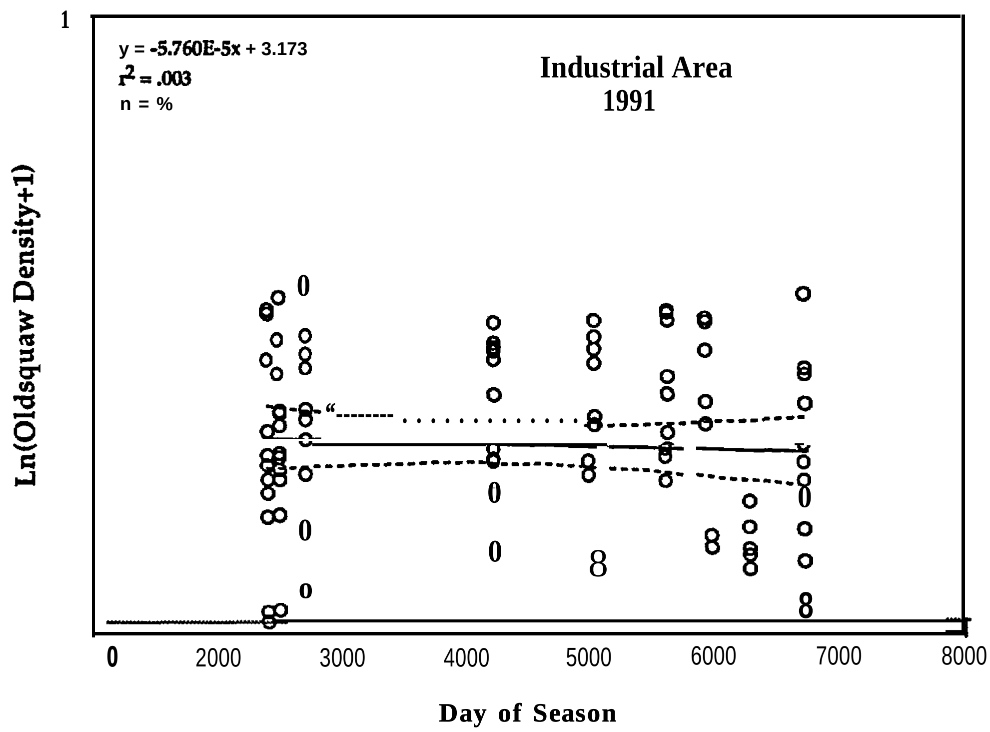


Control Area
1991
n = 96
Ln(Oldsquaw Density+1)
10
8
6
4
2
0
0
1
2
3
Disturbance Level

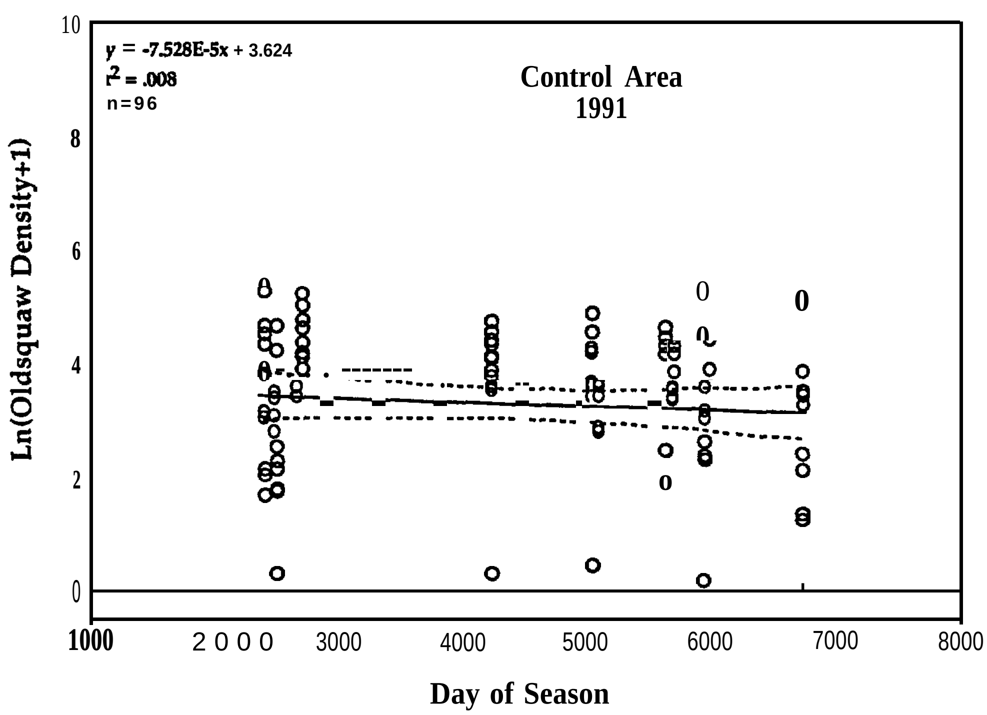
Appendix 6D. Relationship between *oldsquaw density and day of season* in the Industrial and Control study areas in 1990 and 1991. Day 1 is 1 June; the abscissa is scaled to transformed DAY values (X2), e.g., 15 July is day 452 = 2025.





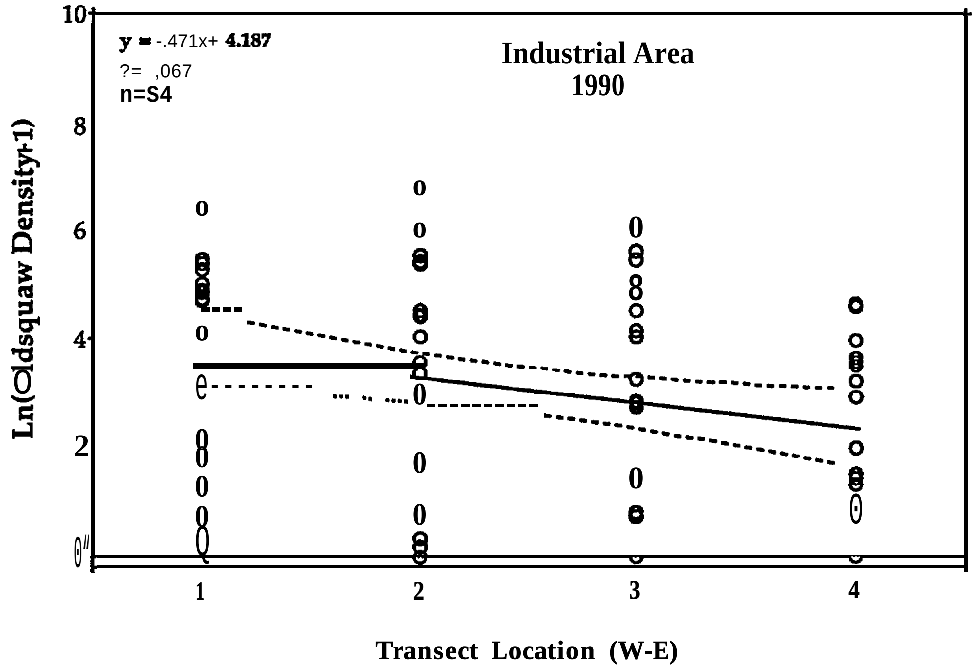


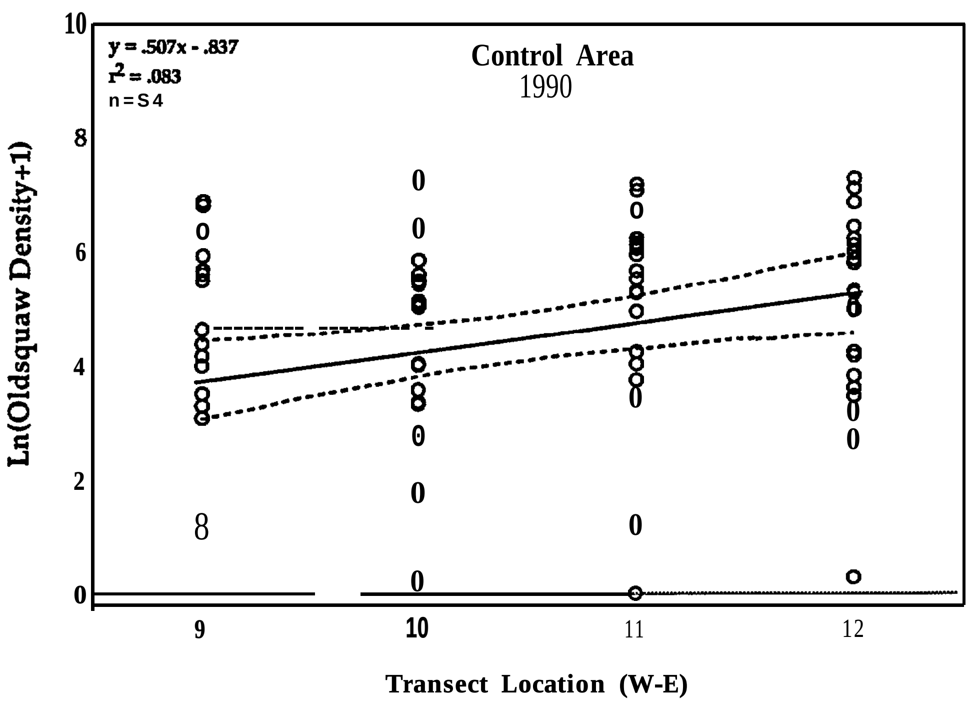
y = -5.760E-5x + 3.173
r2 = .003
n = %
Industrial Area
1991
Ln(Oldsquaw Density+1)
1
0
2000
3000
4000
5000
6000
7000
8000
Day of Season

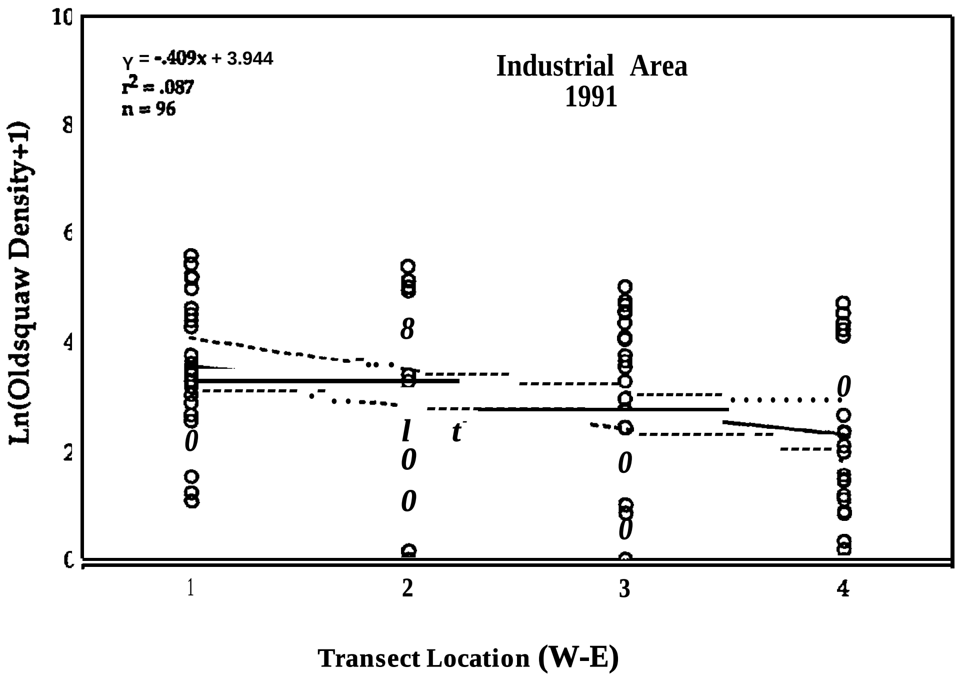


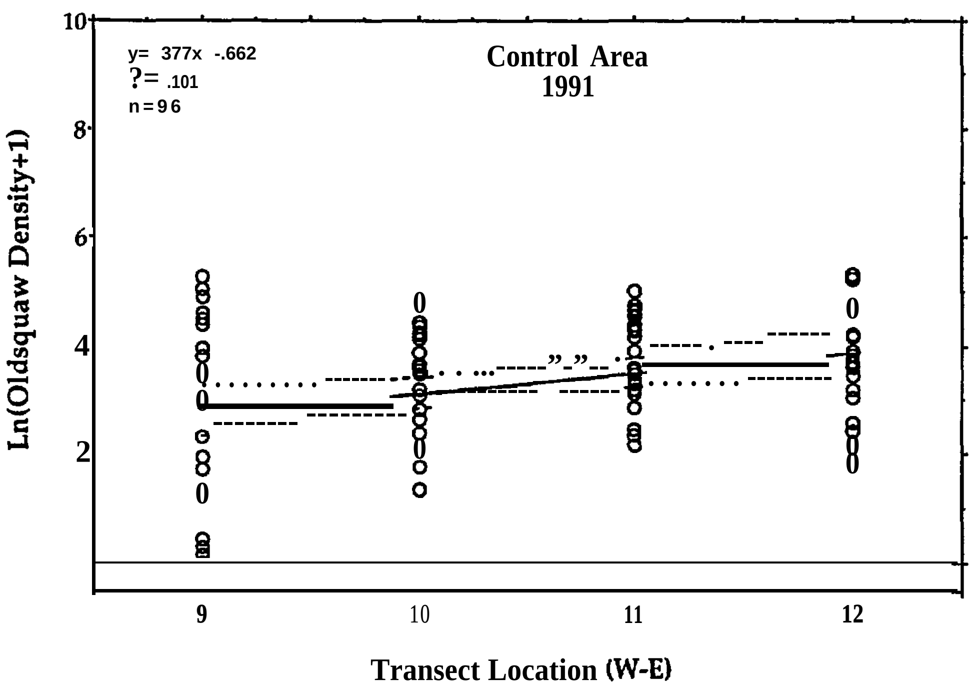
y = -7.528E-5x + 3.624
r2 = .008
n=96
Control Area
1991
Ln(Oldsquaw Density+1)
10
8
6
4
2
0
1000
2000
3000
4000
5000
6000
7000
8000
Day of Season

Appendix 6E. Relationship between *oldsquaw density and transect location* **in the Industrial and Control study areas in 1990 and 1991.**

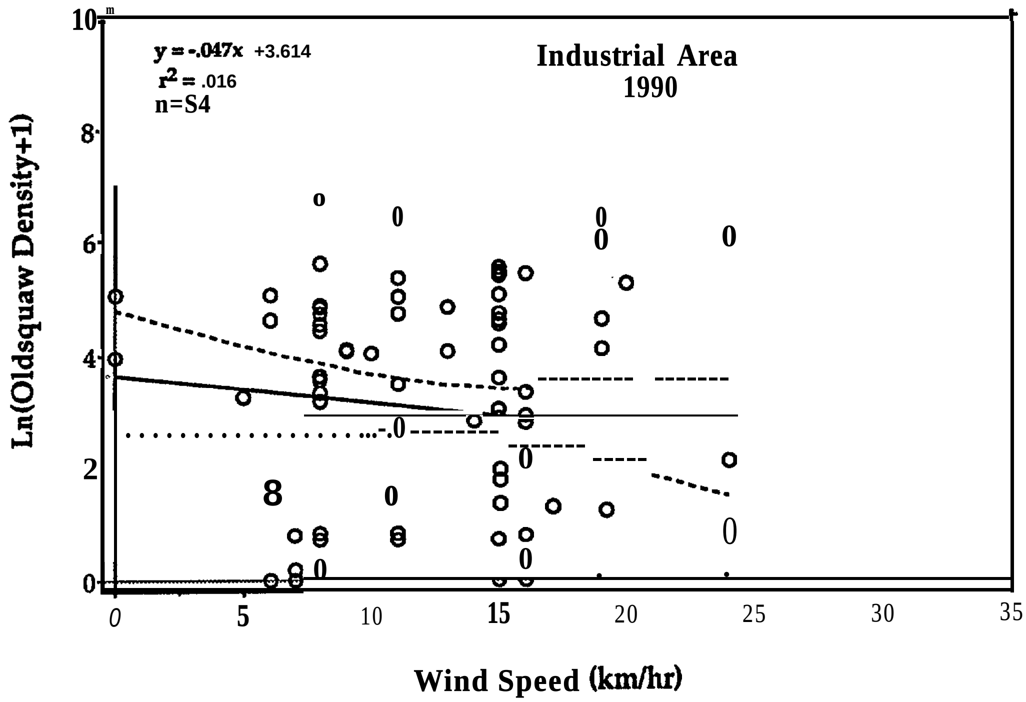


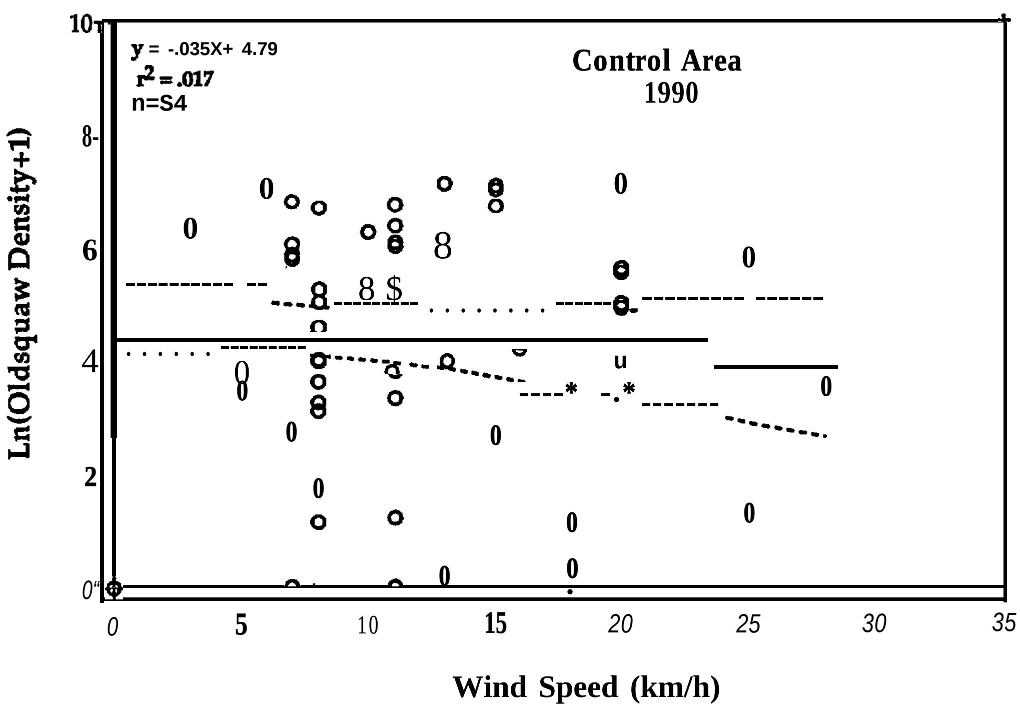


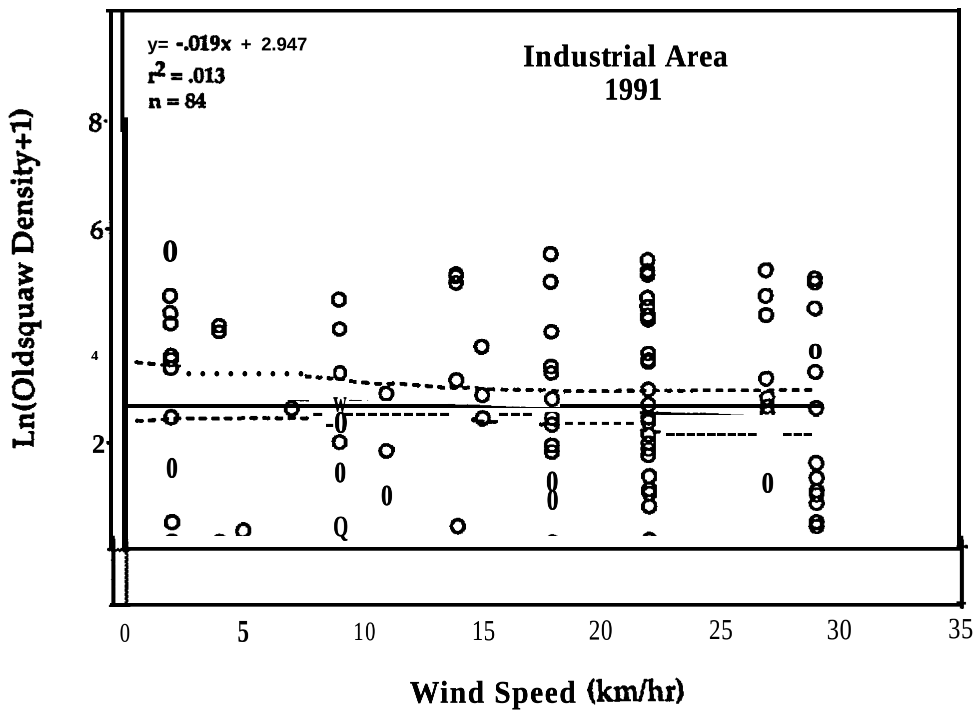

Y = -.409x + 3.944
r^2 = .087
n = 96
Industrial Area
1991
Ln(Oldsquaw Density+1)
Transect Location (W-E)

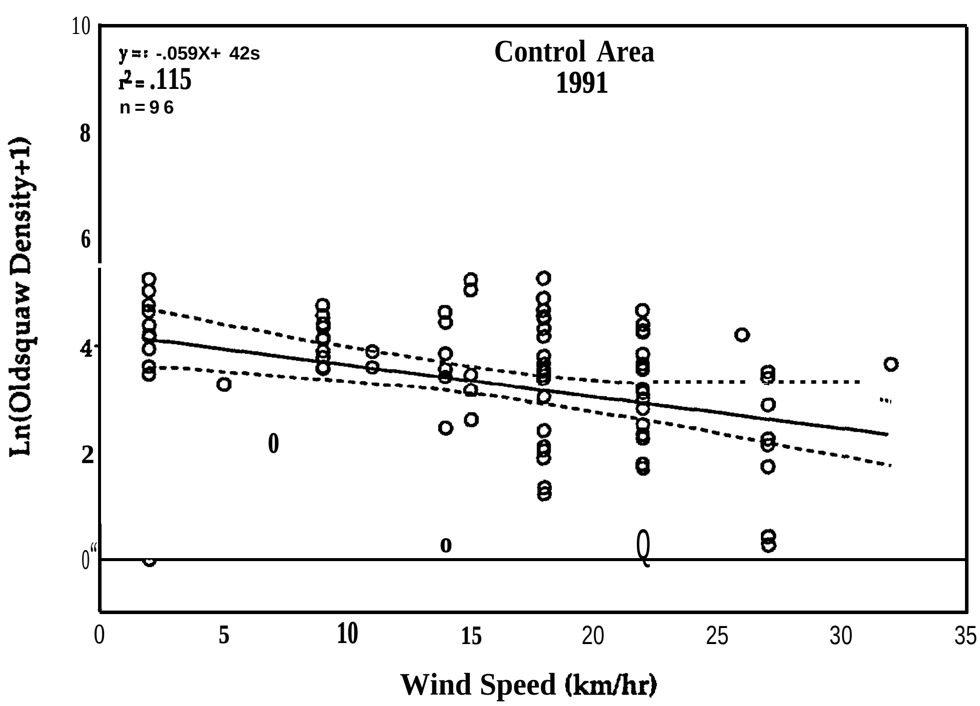

y= 377x -.662
?= .101
n=96
Control Area
1991
Ln(Oldsquaw Density+1)
Transect Location (W-E)

Appendix 6F. Relationship between *oldsquaw density and wind* speed in the Industrial and Control study areas in 1990 and 1991.

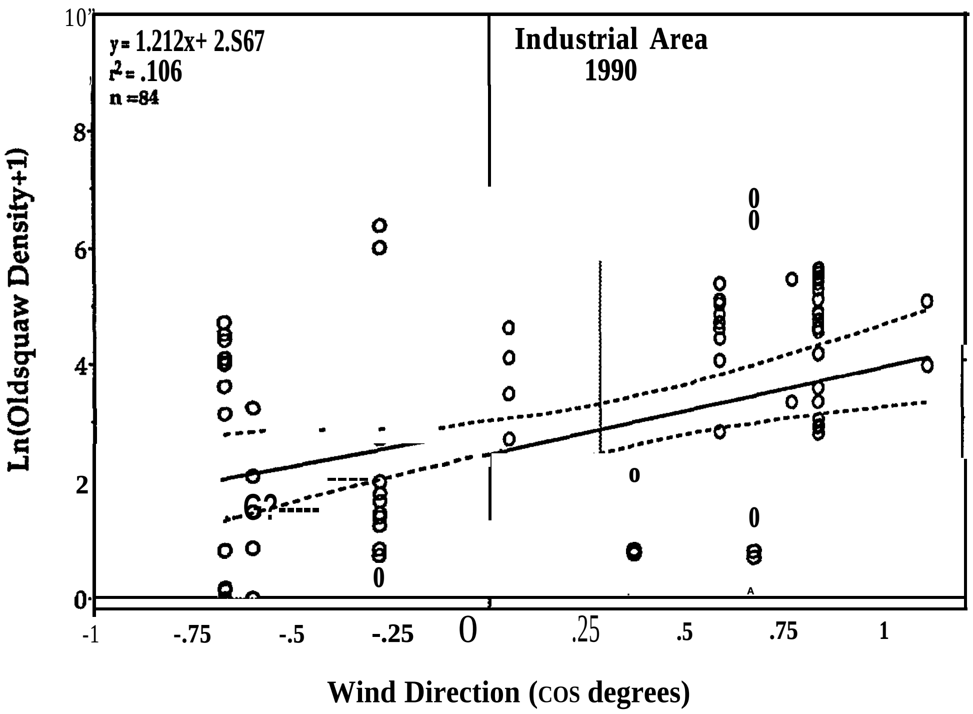


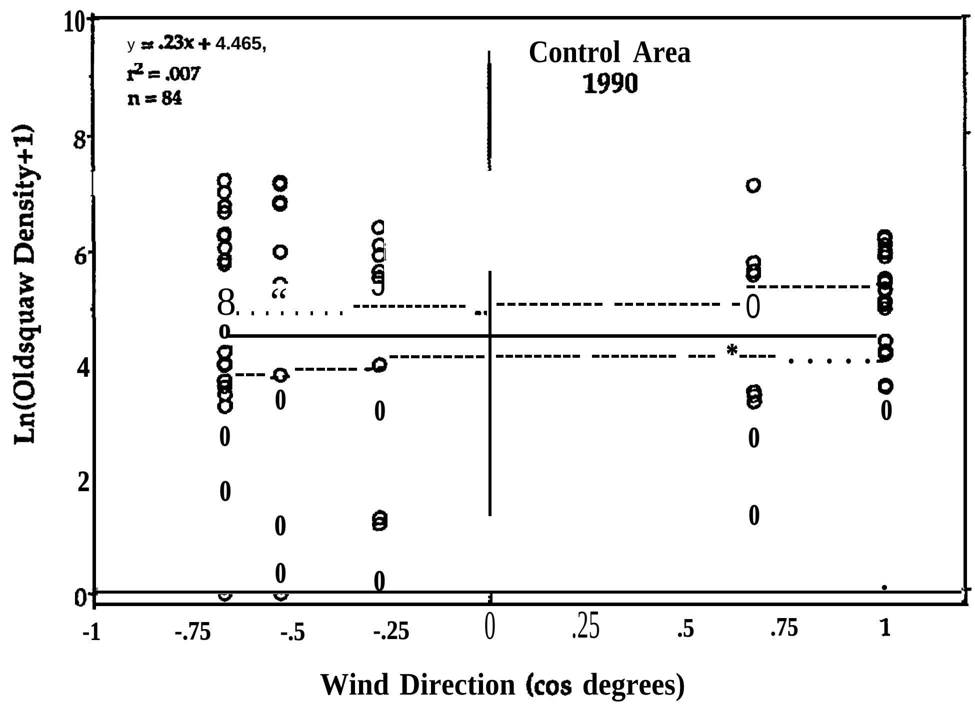


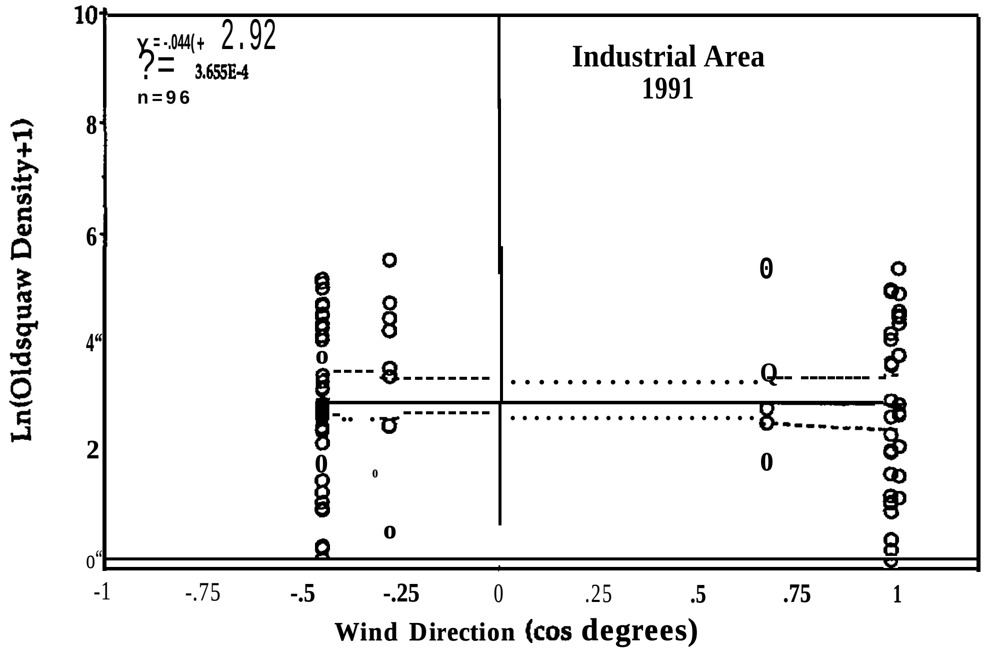

y= -.019x + 2.947
r2 = .013
n = 84
Industrial Area
1991
Ln(Oldsquaw Density+1)
Wind Speed (km/hr)

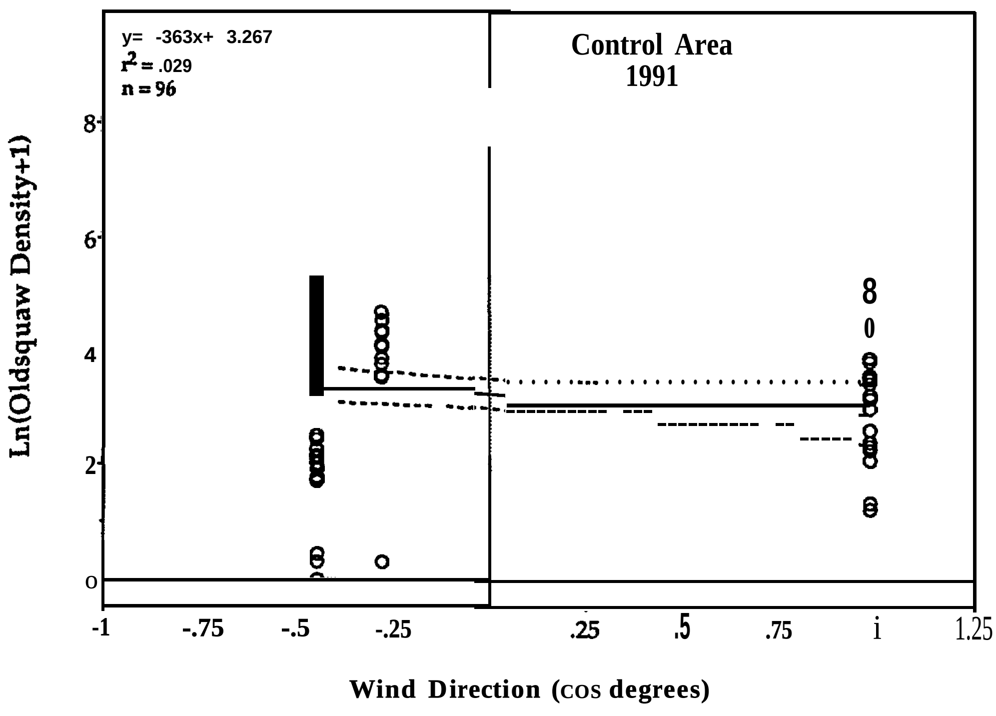

y =: -.059X+ 42s
r2 = .115
n = 96
Control Area
1991
Ln(Oldsquaw Density+1)
Wind Speed (km/hr)

Appendix 6G. Relationship between *oldsquaw density and wind direction* in the Industrial and Control study areas in 1990 and 1991.






y=-.044x+ 2.92
r²= 3.655E-4
n=96
Industrial Area
1991
Ln(Oldsquaw Density+1)
Wind Direction (cos degrees)

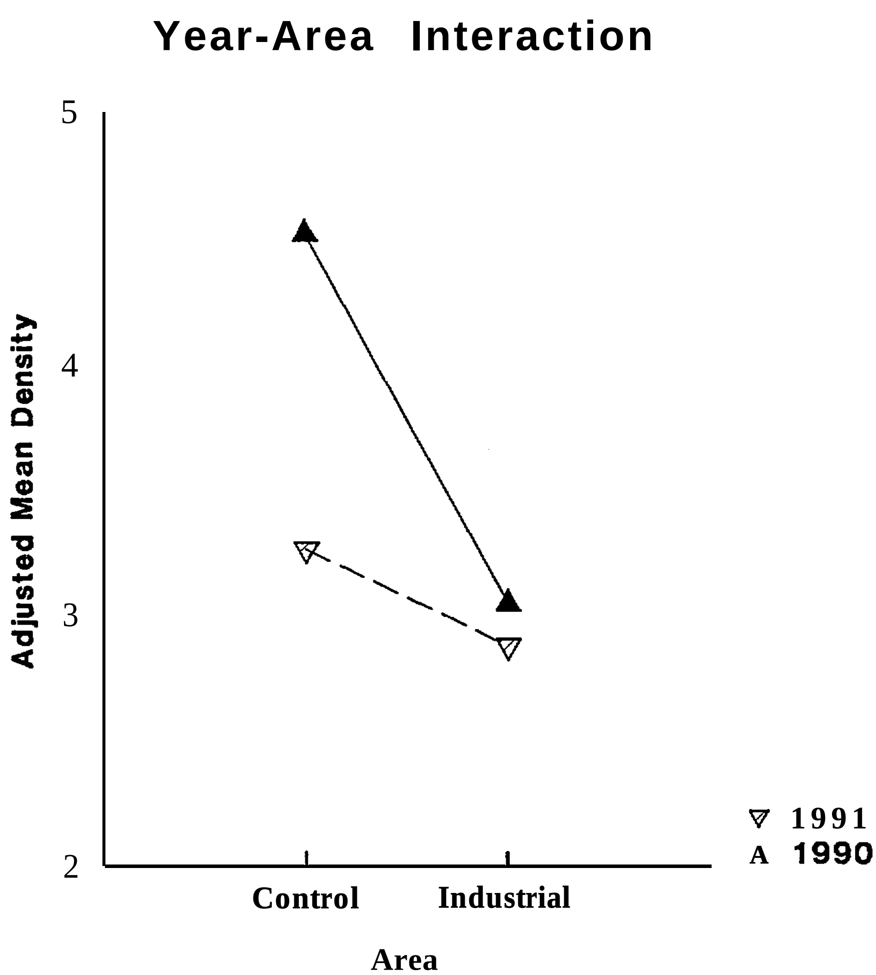

y= -363x+ 3.267
r² = .029
n = 96
Control Area
1991
Ln(Oldsquaw Density+1)
Wind Direction (cos degrees)

Appendix 7. Computed ANCOVA cell means (ln[oldsquaw density + 1], adjusted for wave height) for individual transects in different habitats and study areas sampled in 1990 and 1991.

Sampling Stratum	Year of Study	
	1990 (n=7)	1991 (n=8)
Area 1 (Industrial)		
Habitat 1 (Barrier Island)		
Transect 1	5.350	4.304
Transect 2	5.232	4.397
Transect 3	5.007	4.335
Transect 4	3.882	3.632
Habitat 2 (Mid-lagoon)		
Transect 1	4.550	4.096
Transect 2	3.944	3.134
Transect 3	3.712	3.590
Transect 4	1.908	1.806
Habitat 3 (Mainland)		
Transect 1	1.227	2.127
Transect 2	0.495	1.067
Transect 3	0.607	1.451
Transect 4	0.686	0.629
Area 2 (Control)		
Habitat 1 (Barrier Island)		
Transect 1	6.046	4.468
Transect 2	5.602	3.380
Transect 3	6.161	3.960
Transect 4	6.527	3.937
Habitat 2 (Mid-lagoon)		
Transect 1	0.867	0.165
Transect 2	2.672	3.713
Transect 3	3.153	3.131
Transect 4	3.267	3.215
Habitat 3 (Mainland)		
Transect 1	3.761	2.555
Transect 2	5.077	3.290
Transect 3	5.897	3.853
Transect 4	5.187	3.534

Appendix 8. Computed mean densities of oldsquaws (adjusted for wave height) in Control and Industrial study areas in 1990 and 1991

The figure on this page shows the different relationship between the adjusted mean density of oldsquaws in the two study areas in 1990 and 1991. The 95% error bars for these means (not shown) are well beyond the scale of the ordinate, and therefore show no statistically significant difference between the two sets of means. Nevertheless, the trends in the means for the two areas are subjectively suspicious. Speculation about possible causes of observed differences in oldsquaw density in the two study areas, with only two years of sampling, is a rather tenuous exercise. Nevertheless, the trends suggest that more years of sampling over a wider area would be useful in helping to explain some observed differences in oldsquaw distribution and abundance.



Appendix 9. Numbers and percentages of oldsquaws counted during aerial surveys in nearshore waters of the central Alaska Beaufort Sea, 1977-1984 and 1989-1991.

	Survey Year											
Category	1977	1978	1979	1980	1981	1982	1983	1984	1989	1990	1991	AU Years
Numbers												
1	20695	111594	28598	22777	30597	31927	-	21998	102968	163915	31316	566385
2	58310	141801	36157	27826	48711	46964	6144	28399	110975	220766	61441	787494
3	94461	215199	49456	37549	65768	66794	-	33987	138729	277327	120397	1099667
4	104318	231307	54049	38364	71104	69775	-	34972	149408	312073	138408	1203778
Percentages												
5	90.55	93.04	91.50	97.88	92.50	9.5.73	-	97.18	92.85	88.87	86.99	91.35
6	55.90	61.30	66.90	72.53	68.51	67.31	-	81.20	74.28	70.74	44.39	65.42
7	21.91	51.86	57.83	60.66	46.52	47.80	-	64.72	74.22	59.11	26.01	51.51
8	19.84	48.24	52.91	59.37	43.03	45.76	-	62.90	68.92	52.52	22.63	47.05
9	61.73	65.89	73.11	74.11	74.06	70.31	-	83.56	79.99	79.60	51.03	71.61
10	35.49	78.70	79.09	81.86	62.81	67.98	-	77.46	92.78	74.25	50.97	71.92

1 = No. of oldsquaws on-transect on barrier island transects only
2 = No. of oldsquaws on-transect on all transects
3 = No. of oldsquaws on+off transect on all transects
4 = No. of all binds of all species on+off transect on all transects
5 = Cat. 3/Cat. 4
6 = Cat. 2/Cat. 4
7= Cat. l/Cat. 3
8= Cat. l/Cat. 4
9 = cat. 2/cat. 3
10 = Cat.1/Cat. 2